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Abstract

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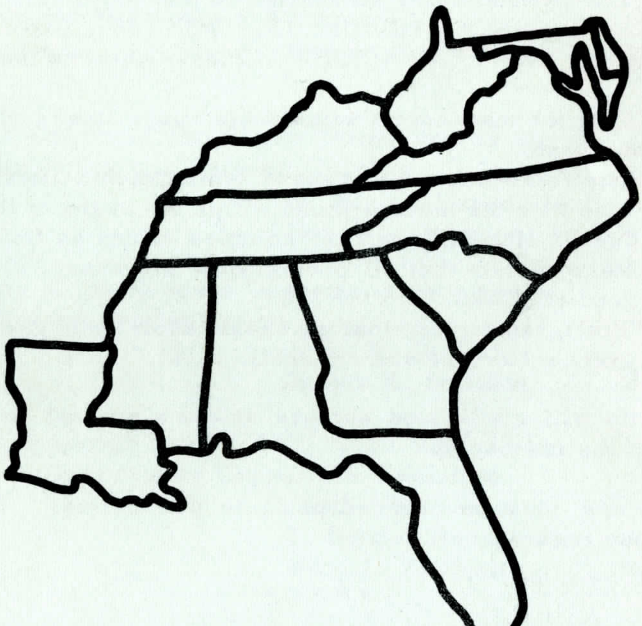

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SOUTHEASTERN GEOLOGY

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Vol. 4, No. 4

1963

CONFIGURATION OF THE CRETACEOUS-TERTIARY BOUNDARY IN THE DELMARVA PENINSULA AND VICINITY

by

Robert R. Jordan
University of Delaware

ABSTRACT

A study of planktonic Foraminifera from nine deep wells has established some reference points on the Cretaceous-Tertiary boundary surface in the Atlantic Coastal Plain in southern New Jersey, Delaware, and the Eastern Shore of Maryland. The Cretaceous-Tertiary boundary is not a plane surface. The strike of the boundary changes from northeast to north-northwest in the vicinity of the Salisbury Embayment. Rates of dip are variable, but all are less than 50 feet per mile. Steeper than average dips appear to be present in north-central Delaware and on the western margin of the Salisbury Embayment.

INTRODUCTION

Any surface which approaches a time-surface is valuable to stratigraphic correlation, especially in areas where, owing to lack of exposures, the stratigraphic column must be defined in the subsurface. The Cretaceous-Tertiary boundary, although actually no more important to correlation than any other time surface, has attached to it a particular interest because of its prominent position in the formal division of geologic time.

Studies concerned with the outcropping sediments and shallow wells have related the Cretaceous-Tertiary boundary to the rock units found at the inner margin of the Coastal Plain. The time boundary may be expected to slope gently seaward with the regional trend for an indefinite distance; however, because of facies changes, the rock units do not continue indefinitely in the down-dip direction. The writer has discussed this problem in connection with the stratigraphy of these rocks in Delaware (Jordan, 1962b). The necessity of utilizing paleontologic as opposed to lithologic criteria in the down-dip extension of the Cretaceous-Tertiary boundary is evident.

Attention has been directed by many workers to the method of determining the Cretaceous-Tertiary boundary by means of planktonic Foraminifera. The studies of Loeblich and Tappan (1957a, b) and Olsson (1960) are particularly relevant to the Atlantic Coastal Plain in New Jersey, Delaware, and Maryland - the area with which the present report is concerned.

Planktonic Foraminifera from nine relatively deep wells have been examined. One of the wells is in southern New Jersey, five are in Delaware, and three are in the Eastern Shore of Maryland (Figure 1). Within this general area there are probably very few additional wells from which adequate information and samples are available. Although it is desirable to know the configuration of the Cretaceous-Tertiary boundary in far greater detail than can be obtained from the present control points, additional refinement will be largely dependent upon the procurement of reliable samples from additional wells.

Acknowledgments

The samples used in this study were widely distributed and the author is grateful to many persons who helped to gather them. Samples from the wells near Salisbury, Berlin, and Ocean City, Maryland were contributed by Horace G. Richards, Curator of Geology and Paleontology at the Academy of Natural Sciences of Philadelphia. S. M. Vauclain and John A. Means of the Sun Oil Company provided samples from two wells near Bridgeville, Delaware. Portions of cores from the well near New Brooklyn Park, New Jersey were obtained through the efforts of Allen Sinnott, District Geologist, and Ellis Donsky, Geologist, of the U. S. Geological Survey Ground Water Branch Office at Trenton, New Jersey, who also read the manuscript and offered helpful suggestions. The other wells discussed herein were logged and sampled by the Delaware Geological Survey with the cooperation of the Delaware District Office of the Ground Water Branch of the U. S. Geological Survey. The support of this project by Johan J. Groot, State Geologist of Delaware is gratefully acknowledged.

LOCATION OF THE CRETACEOUS-TERTIARY BOUNDARY

The so-called "faunal break" of the planktonic Foraminifera has

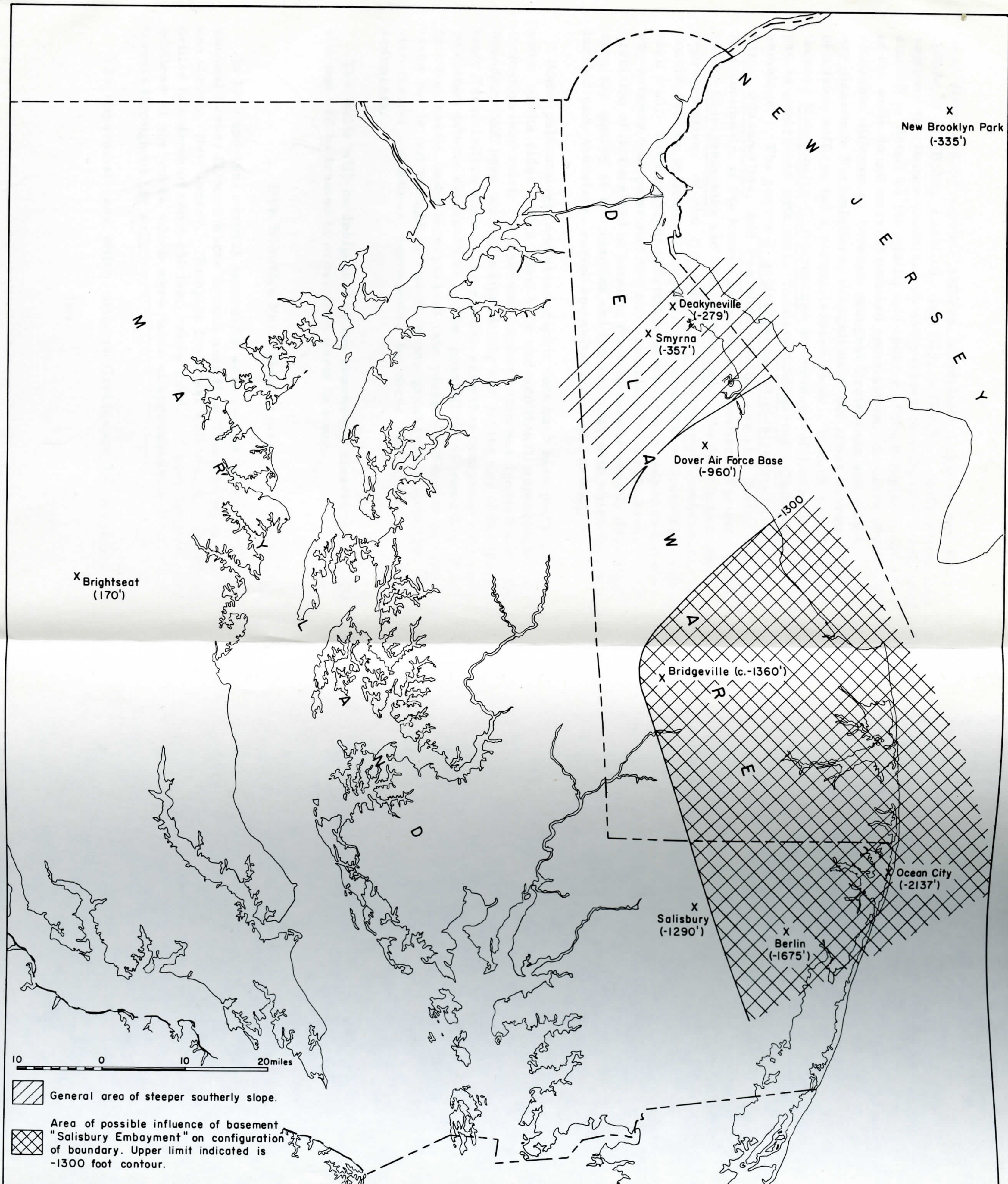

Figure 1. Map showing location of localities studied. Numbers in parentheses indicate altitude of Cretaceous-Tertiary boundary.

been discussed by several authors, especially Loeblich and Tappan (1957a, b) and Bolli, Loeblich, and Tappan (1957). With a few exceptions the faunas examined in the present investigation were not studied in detail as the quality and spacing of the samples from most of the wells do not warrant detailed examination. Because of the considerable differences between youngest Cretaceous and oldest Tertiary planktonic Foraminifera, recognition of the gross characteristics of a fauna suffices for a reconnaissance study. In each well the Cretaceous Heterohelix-Globotruncana assemblage of Loeblich and Tappan is contrasted with their Tertiary Globigerina - Globorotalia assemblage. The genera Rugoglobigerina, Biglobigerinella, Guembelitria, Planomalina, and Pseudoguembelina are also found, more or less commonly, in the former assemblage. Additional Tertiary genera are Globigerinoides and Chiloguembelina. The first appearance of representatives of the Heterohelix - Globotruncana assemblage is considered to indicate the uppermost samples of Cretaceous age in each well. The Cretaceous-Tertiary boundary was judged to lie midway between this point and the next sample (Tertiary) above. The precision of this method of locating the boundary is greatly dependent upon the quality of the samples and the accuracy with which they are labeled and, therefore, varied somewhat from well to well.

Some paleontologic and stratigraphic data have been published for some of the older wells used here and additional unpublished information may exist. All previous information was ignored until the boundary had been placed independently and by the use of the planktonic Foraminifera alone. The results were then compared with such published data as are available. The possibility of reworked Cretaceous fossils being incorporated into younger sediments is recognized but is not thought to result in any great errors under the environmental conditions represented by these fine-grained marine sediments.

The wells will be designated by the community closest to the well site and will be treated in order from north to south.

New Brooklyn Park, New Jersey

In 1960 and 1961 several deep wells were drilled for the U. S. Geological Survey Ground Water Branch near New Brooklyn Park, Camden County, New Jersey. Samples from test well No. 2, which was drilled to a depth of about 850 feet, were used. These samples are portions of the cores which were taken at approximately 10-foot intervals throughout the well.

The uppermost core which contains Cretaceous Foraminifera is from 450-452 feet. The planktonic assemblage is dominated by Biglobigerinella, Rugoglobigerina, and Heterohelix. The next core above (440-442 feet) contains the Globorotalia compressa - Globigerinoides daubjergensis zone of the Danian (Loeblich and Tappan, 1957a, b). The Cretaceous-Tertiary boundary may be presumed to lie between the bottom of the deepest core of Tertiary sediments and the top of the highest core of the Cretaceous sediments, or 446 feet below the level of the well site. As the well was drilled at an elevation of 111 feet the boundary lies at -335 feet at this point. These data are summarized in table 1.

Deakyneville, Delaware

An exploratory water well was drilled under the supervision of the Delaware Geological Survey at Deakyneville which is 6 miles northeast of Smyrna in New Castle County, Delaware. This well was drilled into crystalline rock at 2313 feet. The well was begun late in 1960 and completed early in 1961. Cores were taken at irregular intervals according to lithologic changes and cuttings were collected between cores.

The core from 322-323.5 feet yielded a few rather poorly preserved foraminifers belonging to the genera Heterohelix, Guembelitria, and Biglobigerinella (?), which indicate a Cretaceous age. The next core above is from 297-298.5 feet and contains the Danian Globorotalia compressa - Globigerinoides daubjergensis zone including typical Globigerina and Chiloguembelina. In an attempt to refine the placement of the boundary several samples of cuttings from intermediate depths were examined. It was found that the sample representing the interval 297-303 feet contained the first appearance of Cretaceous forms. The boundary is therefore placed at a depth of 300 feet or 279 feet below sea level.

Smyrna, Delaware

In 1959 a well was drilled to a depth of 585 feet at a point about one mile north of Smyrna, New Castle County, Delaware. The samples are cuttings washed up in the drilling fluid.

The sample representing the interval 390-395 feet contains a few Cretaceous Foraminifera. This is the first appearance of Cretaceous fossils. Below 395 feet they become increasingly numerous. The sample from 370-390 feet contains a variety of Tertiary planktonic Foraminifera including Globigerinoides daubjergensis. The boundary occurs within the 390-395-foot sample at a depth of, say, 392 feet or an altitude of -357 feet.

Dover Air Force Base, Delaware

As part of a ground-water exploration program, the Delaware Geological Survey in 1957 supervised the drilling of a deep well on the Dover Air Force Base approximately 3 miles southeast of Dover, Kent County, Delaware. Cores eighteen inches long were taken at intervals of ten feet throughout the 1422 foot well.

A preliminary description of the stratigraphy of the well was presented by Rasmussen, Groot, and Depman (1958). A detailed study of the planktonic Foraminifera found in the vicinity of the Cretaceous-Tertiary boundary (Jordan, 1962a) has shown that the boundary occurs between 978.5 feet (bottom of the deepest core containing Paleocene Foraminifera) and 987 feet (top of the highest core containing Cretaceous Foraminifera). A depth of 983 feet may be used as this will not err by more than 3.5 feet. The altitude of the boundary here is -960 feet.

The occurrence of a thin bentonite layer in the earliest Tertiary sediments prompted a detailed investigation of the lithology of sediments near the boundary (Jordan and Adams, 1962). No significant differences in the rocks above and below the boundary were found and there appears to be no evidence of an unconformity.

Bridgeville, Delaware

Several exploratory oil wells were drilled near Bridgeville, Sussex County, Delaware in the late 1930's. Samples from two of the wells, obtained from the Sun Oil Company, were used in this investigation. Very small portions of a few cores from the well designated as Apple Orchard D-6 were provided. The rest of the samples from this well and all of those from the well called Russell D-5 are cuttings.

The core at 1330 feet in Apple Orchard D-6 contains planktonic Foraminifera of the _Globorotalia angulata_ zone of Late Paleocene (Loeblich and Tappan, 1957a, b) age. This zone extends into the Lower Eocene according to Olsson (1960). The fauna includes _Globorotalia pseudomenardii_ and _Globorotalia elongata_. Available cuttings for the next deeper thousand feet or more in the well are either barren or contain only Tertiary Foraminifera which are thought to represent contamination from above. Below this, Cretaceous types are found.

It is difficult to place the Cretaceous-Tertiary boundary without more information. It is known that Paleocene-Eocene sediments are present at 1330 feet and also that variegated clays, which suggest the non-marine sediments of the Potomac Formation, elsewhere known to be of Cretaceous age, begin at about 1695 feet. Detailed work was done on the well at Dover Air Force Base and it has been determined that a fauna similar to that found in Apple Orchard D-6 at 1330 feet is present there at about 70 feet above the Cretaceous-Tertiary boundary. Under the circumstances it seems reasonable to estimate the depth of the boundary at Bridgeville by adding 70 feet to 1330, placing it at about 1400 feet. Various elevations are given for the well site, the exact location of which is no longer known, but elevations in the area range only between 30 and 50 feet. In view of the crudity of the other approximation, an elevation of 40 feet is acceptable. This yields -1360 feet as the elevation of the Cretaceous-Tertiary boundary in this well.

Samples from the Russell D-5 are all cuttings and some are obviously contaminated. The deepest sample definitely belonging to the Tertiary is from a depth of 1350-1360 feet and the first Cretaceous Foraminifera are found in the 1390-1400-foot deep sample. Although this is not very precise, these figures suggest confirmation of the estimate for the Apple Orchard well. The use of information from the two wells provides some evidence for the placement of the boundary at an elevation of about -1360 feet at Bridgeville. This is deeper than has been reported by Richards (1945a) and Rasmussen, Wilkens, Beall, and others (1960).

Ocean City, Maryland

This well is located 4 1/2 miles north of Ocean City, Worcester County, Maryland. The well was drilled in 1946 by the Standard Oil Company to a depth of 7710 feet, and is sometimes referred to as Maryland Esso No. 1. It has been described by Anderson (1948).

Small samples of cuttings were available for study. Strictly on the basis of first appearance of the Cretaceous planktonic Foraminifera, the Cretaceous-Tertiary boundary is placed within the interval 2140-2150 feet. All samples above this are Tertiary. Samples from 2140 to 2170 feet contain Cretaceous Foraminifera. No Cretaceous Foraminifera, however, are found in the next several samples below 2170 feet although Tertiary forms are common throughout the interval. This is thought to represent an unfossiliferous Cretaceous interval, the samples of which have been contaminated by Tertiary fossils from higher in the well. There seems to be no reason to question the validity of the samples and the highest appearance of Cretaceous Foraminifera may be accepted and the boundary placed at about 2145 feet or an elevation of -2137 feet. This is in agreement with Anderson's conclusion which was based on quite different evidence: "On the basis of lithology the contact between the Eocene and the Upper Cretaceous is placed within the interval 2100 and 2150 feet" (Anderson, 1948, p. 93). This is also not greatly different from the figure of -2080 feet given by Spangler and Peterson (1950) or the similar figure of Richards (1948).

Salisbury, Maryland

In 1944 the Ohio Oil Company drilled the L. G. Hammond Well No. 1 about 6 miles east of Salisbury, Wicomico County, Maryland. Detailed accounts of the sedimentary petrology, paleontology, and stratigraphy of the well are found in the report by Anderson (1948).

Small portions of cores were provided for study. The core from 1360-1370 feet is the uppermost core containing Cretaceous planktonic Foraminifera. The assemblage includes <u>Globotruncana</u>, <u>Biglobigerinella</u>, <u>Rugoglobigerina</u>, and <u>Heterohelix</u>. The next core above, 1350-1360 feet, contains the Tertiary genera <u>Globigerina</u>, <u>Globorotalia</u>, and <u>Globigerinoides</u>. <u>Globigerinoides daubjergensis</u> is present, an indication that these are indeed very early Tertiary sediments.

Cushman (in Anderson, 1948) studied the Foraminifera from this well. He concentrated, however, on benthonic Foraminifera. He indicated that the interval from 1320 feet to 1350 feet was Paleocene (p. 226). The sample from 1350-1360 feet "...appears to have a mixture of Paleocene and Cretaceous species" (p. 244). Thus, the results of the present study agree exactly with the earlier work of Cushman which was performed before the general recognition of the usefulness of the planktonic Foraminifera in the determination of the Cretaceous-Tertiary boundary. This is also essentially in agreement with Richards (1945b, 1948) who placed the contact at 1380 feet.

Allowance for the altitude of the well site places the boundary in the Salisbury well at -1290 feet.

Berlin, Maryland

The Socony-Vacuum Oil Company drilled this well, which was designated James D. Bethards No. 1, 5 miles southwest of Berlin in Worcester County, Maryland in 1945. Anderson (1948) has described the well and the stratigraphy.

Well	Surface Elevation	Depth to Boundary	Elevation of Boundary
New Brooklyn Park, N.J.	111'	446'	-335'
Deakyneville, Del.	21'	300'	-279'
Smyrna, Del.	35'	392'	-357'
Dover Air Force Base, Del.	23'	983'	-960'
Bridgeville, Del.	c. 40'	c. 1400'	c.-1360'
Ocean City, Md.	8'	2145'	-2137'
Salisbury, Md.	70'	1360'	-1290'
Berlin, Md.	30'	1705'	-1675'
Brightseat, Md.	170'	Outcrop	170'

Table 1. Location of the Cretaceous-Tertiary Boundary

The cuttings examined for planktonic Foraminifera show that the highest occurrence of Cretaceous fossils is in the sample from 1700-1710 feet. The sample immediately above (1690-1700 feet) contains only Tertiary Foraminifera, which suggests placement of the boundary at a depth of 1705 feet. This agrees essentially with Anderson's statement (1948, p. 85) "On foraminiferal evidence, Cushman has placed the Eocene-Cretaceous boundary in the interval represented by the ditch samples from 1670 to 1680 feet. The core sample from 1709 to 1728 feet contained Cretaceous foraminifera". Richards (1948) listed the boundary at "1710?" feet. Considering the boundary to lie at a depth of about 1705 feet and the well site to be at an altitude of 30 feet yields an altitude of the boundary at this point of -1675 feet.

DISCUSSION

The usefulness of the planktonic Foraminifera in the determination of the Cretaceous-Tertiary boundary is now well recognized and the present investigation may serve to reemphasize the applicability of the method in this portion of the Atlantic Coastal Plain. One must agree, in principle, with the statement of Loeblich and Tappan (1957b, p. 174) that: "There is no longer any reason for questionable correlations of marine deposits at the Cretaceous-Tertiary boundary."

There is sufficient variation in the character of the rocks in which the Cretaceous-Tertiary boundary is found so that it is clear that the time surface cannot be equated with a particular lithology or change in lithology. It may also be noted that the presence of an unconformity at the boundary is not evident; on the contrary, deposition appears to have been continuous.

Both formation boundaries and time surfaces in the Atlantic Coastal Plain are often characterized as plane surfaces which strike northeast and dip gently to the southeast. This is perhaps necessary, and commonly true as a generalization, but such a concept may be misleading in that it creates an oversimplified picture of stratigraphic and structural relationships within the Coastal Plain rocks. Using the few known points on the Cretaceous-Tertiary boundary listed above, some conclusions regarding the configuration of this surface may be drawn. One additional control point may be added from the outcrop at Brightseat, Maryland near Washington, D. C. (Bennett and Collins, 1952). This locality was also examined and sampled and, from the topographic map, the altitude of the contact is judged to be about 170 feet.

The graphic solutions for strike and dip between various combinations of the control points yield a range of strikes and dips. A kind of <u>average</u> strike and dip is given by the near extreme points, New Brooklyn Park, New Jersey, Salisbury, Maryland, and Brightseat, Maryland. These yield a strike of about N49°E and a dip to the southeast of about 18 feet per mile. Other calculations involving the wells at Dover Air Force Base, Bridgeville, Salisbury, Berlin, and Ocean City give strikes nearly to the north and dips to the east of between 30 and 40 feet per mile. Between the well at Dover and points up-dip the strike is approximately northeast but the dip to the southeast increases to almost 45 feet per mile. The strike of the Cretaceous-Tertiary boundary ranges from about N24°W to N53°E over the area of study.

Although it is tempting to contour the top of the Cretaceous rocks on the map, the amount of available control does not seem to warrant this detail. Consideration of the data does, however, indicate several features of the configuration of the Cretaceous-Tertiary boundary, the locations of which are indicated in figure 1.

Between the approximate strike line from New Brooklyn Park to the Deakyneville-Smyrna area and points 15 miles or so to the southeast, as represented by Dover Air Force Base, the boundary slopes more steeply to the southeast than it does elsewhere to the east and southeast. The slope between Smyrna and Dover Air Force Base (not directly in a dip direction) is more than 40 feet per mile. It is interesting to note that a "structural form line" in the Chesapeake-Delaware basin of Murray (1961, p. 80) appears to pass between these points.

Between Dover Air Force Base and Salisbury the slope decreases greatly as this direction is almost along the strike. It should be noted that at Bridgeville the boundary is actually at a greater depth than at Salisbury. This and the dip to the east indicated by the Salisbury, Berlin, and Ocean City wells suggest the existence of some depression situated along the eastern margin of the southern Delmarva Peninsula which may curve to the northwest in southern Delaware. This "low" may be a reflection of the basement depression having the same general configuration. This has been called by Richards (1948, p. 54) the Salisbury Embayment. The Salisbury Embayment has also been discussed by Rasmussen and Slaughter (1955). It appears that Salisbury does not lie in the axial portion of the structure as it appears on the Cretaceous-Tertiary boundary, but, rather, to the southwest of the axis as it is presently understood. This change in strike of the basement rocks has been recognized for some time and is clearly shown by the maps of Richards (1945a) and Richards, Olmstead, and Ruhle (1962). It is also shown by the structure maps of Spangler and Peterson (1950) of the "Monmouth" (top of the Cretaceous) and several older units. A review of these features may be found in Murray (1961).

Dryden (1935) has discussed the structure of the younger Coastal Plain units in Southern Maryland and his remark regarding the Eocene-Miocene unconformity of that area is equally applicable to the Cretaceous-Tertiary boundary of the present study area: "...there is something of interest in the fact that this surface does not have the traditional strike and dip supposedly possessed by all the elements of the Coastal Plain" (Dryden, 1935, p. 325). The known structures of the middle Atlantic Coastal Plain may be subtle but structures are not lacking.

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NATURE AND ORIGIN OF THE SLUMP STRUCTURES IN THE BLACK MINGO FORMATION OF SOUTH CAROLINA

by

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ABSTRACT

The Black Mingo Formation (lower Tertiary) of South Carolina contains beds of mudrock that may on outcrop be hard and break with a conchoidal fracture. This material is locally called "fullers earth" because of its oil clarification properties. The hard mudrock is composed predominantly of ordered opal (unidimensional disordered cristobalit e) with some montmorillonite usually present.

In dissected areas the hard mudrock may locally be partially destroyed by removal of the opal with a resulting decrease in volume. Along a given bed some of the hard mudrock is left undisturbed and occurs as rounded and irregular pods. Between the pods the overlying sediments slump to produce small synclines. Over the pods small anticlines may form because of the let down of the sediments on either side.

The destruction of the mudrock is not complete. Montomorillonite is left behind to form a residuum of soft clay. The opal is assumed to have been removed by ground water because slump structures have been noted in outcrop only in dissected areas where the ground water

gradient would be expected to be high (elsewhere the hard mudrock apparently does not have associated slump structures), and drilling indicates that away from larger streams and at a depth there are no collapse structures and no formation of the montmorillonite residuum. Published experimental data indicate that silica can be dissolved by waters of essentially any pH.

INTRODUCTION

The basal Tertiary unit in South Carolina is the Black Mingo Formation. It locally contains a bleaching clay ("fullers earth"). A study of the nature and occurrence of the bleaching clay was started in 1959 by L. N. Smith of the Division of Geology, South Carolina State Development Board. In 1961 the senior author included the bleaching clays in a broad study of the bedded clays of South Carolina. In the course of this study it was recognized that the unusual structures found locally in outcrops of the Black Mingo Formation were formed as a result of collapse.

Acknowledgements

This project was in part supported by the Division of Geology, South Carolina State Development Board. Most of the analytical work was supported by a grant from the National Science Foundation made to the senior author. L. N. Smith did much of the ground work on the study of two key outcrops. He also supplied the authors with much background information on the Black Mingo Formation. Gil Robinson, Ceramic Engineering Department, Clemson College, made the physical measurements of Table 1.

BLACK MINGO FORMATION

The Black Mingo Formation outcrop area forms an irregular belt that trends east-west across a part of the State of South Carolina and includes parts of Georgetown, Williamsburg, Clarendon, Sumter, Richland, Calhoun, Lexington and possibly Aiken counties (Figure 1).

The formation is of early Tertiary age. Cooke (1936, p. 40) cor-

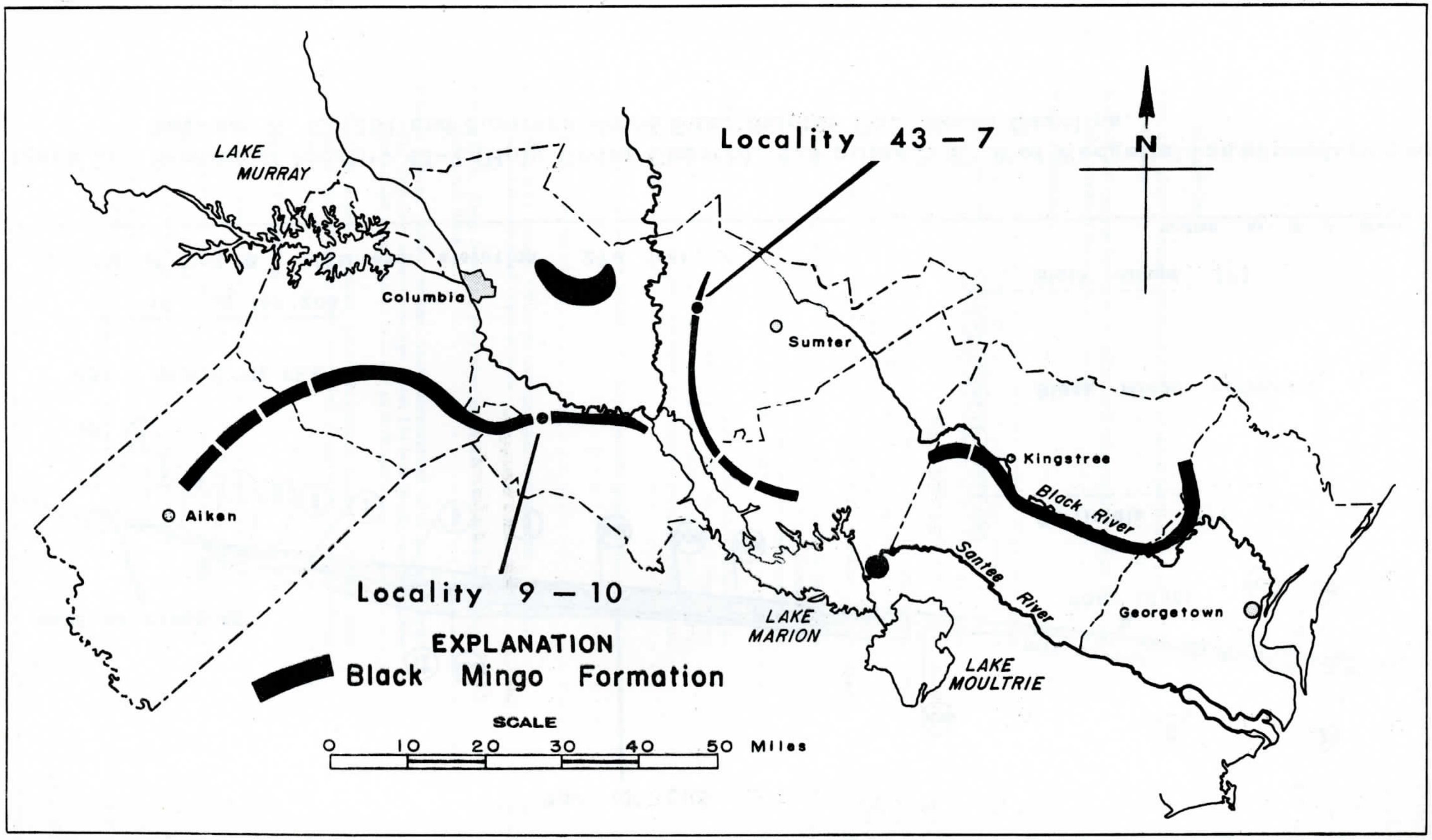

Fig. I. Approximate outcrop of Black Mingo Formation (Lower Eocene) in South Carolina.

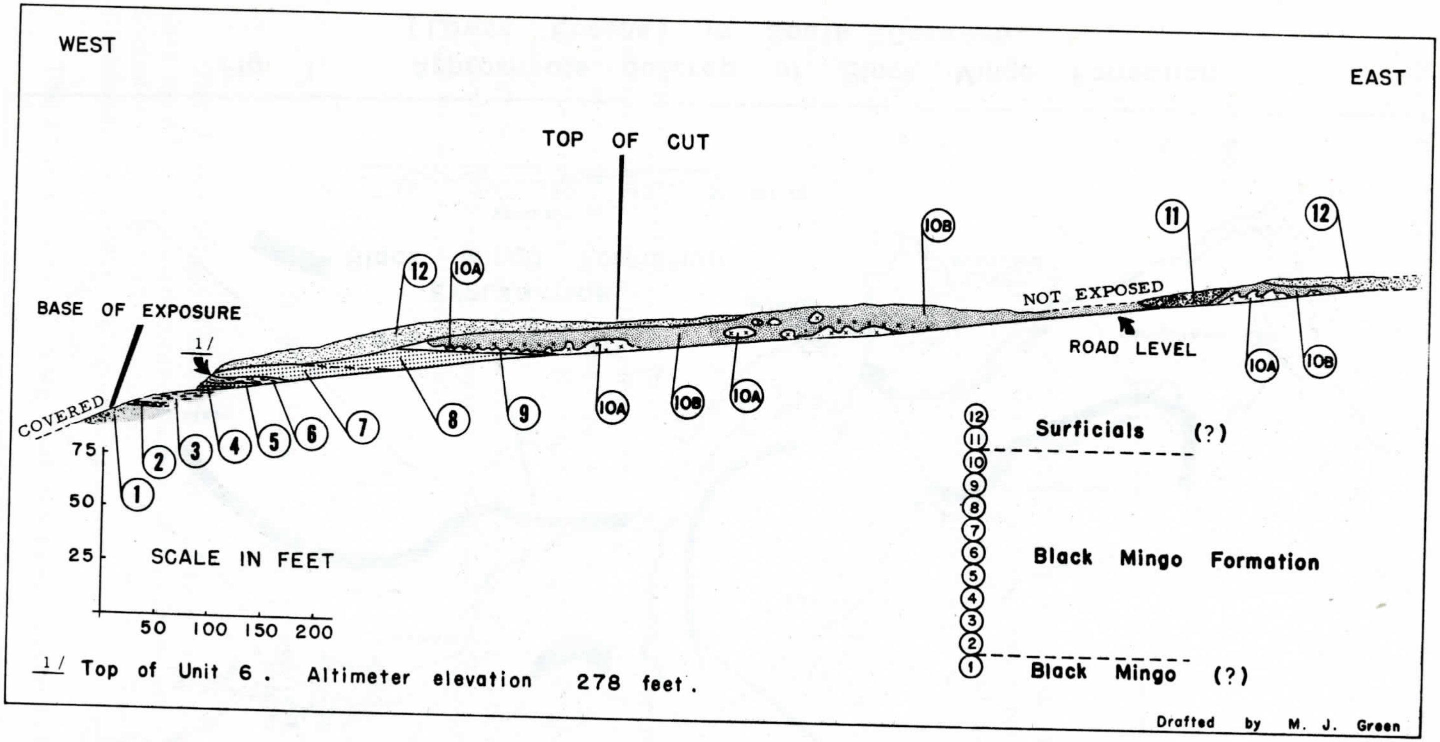

Figure 2. Section at locality 43-7 (Holy Cross Church), 4.4 miles N 8° W of Wedgefield on secondary road between S. C. 261 and Sumters Home Site, Sumter Co., South Carolina.

Explanation of Figure

Unit	Description	Thickness in (Ft.)
Pleistocene(?)		
	Top of Road Cut	
12.	Sand and clayey sands; oxidized red; scattered pebbles to 1/2 inch in diameter	0-10
11.	Medium and coarse loose sand; white with thin regular brown iron and clay banding; local pocket only	0-5
Eocene (Black Mingo Formation)		
10B.	Silt to fine to very fine sand containing thin laminae of greenish gray silty clay; grades laterally and vertically within distances of a few feet into silty mudstone ("fullers earth"); in places contains layers up to several feet thick of brown plastic clay residuum (similar to Unit 9); lower contact highly irregular over pinnacles and swales of 10A	
10A.	Mudstone ("fullers earth"); buff (weathered) to dark gray; conchoidal fracture; upper contact highly irregular forming pinnacles and swales; weathers to brown plastic clay residuum (Unit 9); clay size minerals mostly ordered opal and montmorillonite	45
9.	Silty plastic clay, mottled red-brown-gray; appears to be a residuum of Unit 10A; contact irregular and undulatory, lower contact flat and essentially undisturbed; clay size minerals are montmorillonite, kaolinite, illite, goethite and septechlorite(?)	2 ±
8.	Fine to very fine sand, well sorted, slightly glauconitic; contains abundant thin laminae of greenish gray silty clay; buff where unweathered but orange-red on weathered outcrop; clay size minerals (oxidized portion) kaolinite, montmorillonite, goethite, illite and septechlorite(?)	10
7.	Fine to coarse sand and green silty clay; sparsely glauconitic; oxidized to over-all red color	5
6.	Clay, gray, flaky fissility	2
5.	Fine sand, well sorted; yellowish orange; sparse glauconite; 1-3 inch iron oxide cemented layer at base	2
4.	Clay, gray, flaky fissility; clay size minerals are montmorillonite with some illite	2
3.	Fine to coarse yellow orange sand interlayered with greenish gray silty clay; clay layers average about 1/4 inch thick; sand units are thicker and predominate in lower part of unit	7
2.	Medium to coarse grained quartz-cemented sand (buhrstone) with sparse to moderate hashlike shell fragments, some branching corals	1
Eocene(?) (Black Mingo [?] Formation)		o [?o]
1.	Fine to very coarse argillaceous to very argillaceous sand; light to medium gray; the clay matrix causes the gray color and in places predominates so the unit is sandy clay locally; contains sparse white grains of kaolinized feldspar; clay size minerals are kaolinite, montmorillonite, clay mica and septechlorite(?)	5 ±
	Covered interval at lower end of small borrow pit. Elevation of top of Unit is 278' (altimeter).	

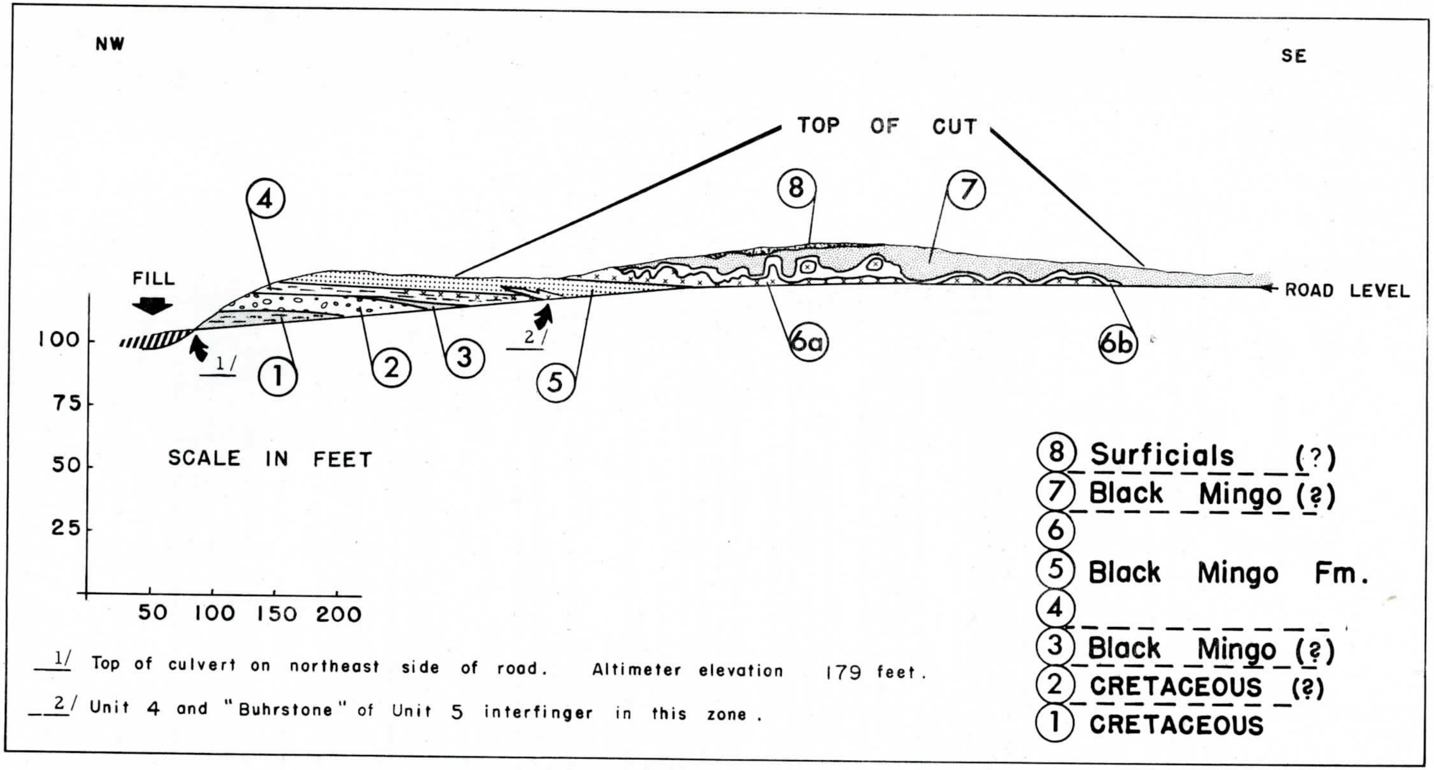

Figure 3. Section at locality 9-10 (Little Beaver Creek), 9.4 miles NW of St. Matthews and 2.95 miles N 75° W of Hammond Cross Roads on County Road No. 173, Calhoun Co., South Carolina.

Explanation of Figure

Pleistocene(?)		**Thickness in (Ft.)**
	Top of Road Cut	
8.	**Loose medium to coarse sand with scattered quartz pebbles up to about 1/2 inch in diameter; gray to light yellow brown; lower surface irregular with relief up to 3 feet**	**0-3**
Pleistocene(?) or Eocene(?) (Black Mingo [?] Formation)		
7.	**Oxidized fine to coarse clayey sand with scattered pebbles and clay balls; yellow brown to brick red, reticulate mottling at base; thickness highly variable because of irregular collapse of underlying units**	**1-10**
Eocene (Black Mingo Formation)		
6B.	**Silty plastic clay; brown; grades into unit 6A and appears to be a weathering product of it; clay size minerals are montmorillonite, kaolinite, illite, goethite and septechlorite(?), sample close to 6A contains ordered opal**	**0-5**
6A.	**Porous mudstone (Fullers Earth) with conchoidal fracture; buff (weathered) to dark gray, liesegang rings of iron staining common; occurs as pods and irregular bodies with a clay residuum (6B) developed between pods. Upper contact highly irregular and characterized by pinnacle and swale topography, lower contact essentially flat and undisturbed; clay size minerals are ordered opal, montmorillonite and illite.**	**1-15**
5.	**Fine to medium sand, glauconitic; yellowish brown to orange; medium scale cross-stratification; thin shell hash (buhrstone) beds (to 1 ft.) and thin seams of gray-green clay; a large shell hash lens (10' x 4') interfingers at base with unit 4; shell hash at base contains poorly preserved corals and small pelecypod fragments**	**5.5-10.5**
4.	**Thin-bedded grayish black mudrock and oxidized moderate yellowish brown glauconitic sd; sd. layers typically 2 cm. thick and clay layers 8 cm. thick; carbonaceous but carbon content decreases upward; upper portion is similar in appearance to unit 6A; clay size minerals from lower portion of unit are montmorillonite, illite, and kaolinite**	**4-6**
3.	**Medium dark gray medium to coarse sd. with irregular layers and blebs of grayish black clay; scattered pebble size balls of white clayey sand and angular feldspar grains concentrated toward base; contains minor tiny grains of pyrite or marcasite and gives slight SO_2 odor; fills shallow channel in underlying unit 2B and extends downward into it in fingerlike worm or mollusk borings several inches deep, small quartz pebbles present in the bottom of some of these borings**	**0-3**
Upper Cretaceous(?) (Tuscaloosa [?] Formation)		
2B.	**Coarse to very coarse clayey sand and fine gravel; blue gray to yellow gray where weathered; [1/] contains abundant jarosite where weathered; where unoxidized contains pyrite or marcasite in association with finely divided carbonaceous material and gives off strong SO_2 odor; cross-stratification is planar, tabular, straight, high angle ($\overline{30}^{o}$) medium scale with southerly to southeasterly dips; feldspar grains (to 1/2 inch) are strongly kaolinized to almost fresh**	**3 ±**
2A.	**Same as 2B but lacks carbonaceous material and sulphide minerals; a creamy gray mottled maroon**	**5 ±**
Upper Cretaceous (Tuscaloosa Formation)		
1.	**Sandy (medium to very coarse) massive clay; mottled gray-white-purple-pink; contains small pickets (inches across) of coarse sand and fine gravel**	**5 ±**

Base covered
Elevation of top of culvert at base of exposure is 179' (altimeter)

1/ Note - blue gray is essentially unoxidized. Yellow gray type is oxidized.

relates the Black Mingo with the Wilcox (Eocene) of the Gulf Coast. A Paleocene age for a part of the formation has been suggested by Cooke and MacNeil (1952, p. 19).

The black Mingo Formation overlies various formations of Cretaceous age. In and west of Sumter County the underlying unit is usually the Tuscaloosa Formation. In Williamsburg and Georgetown counties the underlying unit is reported to be the Peedee Formation (Cooke, 1936, map). The Black Creek Formation may locally occur between the Tuscaloosa and Black Mingo formations.

The overlying formations include the Santee Limestone (middle and upper Eocene), various sands of Claiborne age, sands and limey sands of Miocene (Duplin) age and younger surficial sands and gravels.

In general, outcrops of the Black Mingo Formation occur along streams and roadcuts leading down to the streams. The best exposures are found in the dissected areas adjacent to the Santee, Congaree, and Wateree rivers.

The two best outcrops for studying slump features are Locality 43-7 (Figure 2) in Sumter County and Locality 9-10 (Figure 3) in Calhoun County.

Lithology

The most characteristic unweathered rock type of the Black Mingo Formation is dark gray mudrock, but beds of poorly sorted grayish glauconitic sand are common. The mudrock may be quite pure but it usually is silty and is commonly quite sandy. Samples from auger holes drilled in the downdip portion of the outcrop area show that the unweathered mudrocks and sands may be calcareous. Calcium carbonate has been found in none of the updip exposures and in few, if any, updip auger holes. Limestone is present in the Black Mingo in downdip areas.

"Fullers Earth"

Outcrops of the Black Mingo Formation may contain beds of hard mudrock that has oil clarification properties. Attempts have been made from time to time in the last 50 years to market the mudrock as a commercial fullers earth. These have been unsuccessful mainly because of the economic marginal nature of the product.

Clay Size Mineralogy

Mineralogically the clay size fraction of the hard mudrock ("fullers earth") consists largely of ordered opal (unidimensional disordered cristobalite) and montmorillonite. Considering the mudrocks of the formation as a whole, clay mica (illite, glauconite, muscovite) occurs in almost all samples studied. Kaolinite was found to be absent in 16 of 48 samples studied and generally occurs only in small amounts in the remaining samples. Twelve of the samples contain no ordered opal.

Montmorillonite is generally the most abundant of the clay size minerals in the formation. In the typical hard "fullers earth" that shows a conchoidal fracture, opal occurs in the greatest amounts. A few samples of essentially pure opal have been examined. These have a low bulk density, a high porosity and the best developed conchoidal fracture (Table 1).

A detailed study of the nature and origin of the opal in the Black Mingo Formation will be published at a later date.

SLUMP STRUCTURES

Slump structures usually occur as small scale synclines and anticlines. Synclines may be as large as 15 or 20 feet across. Anticlines are generally 5-10 feet across. A small (2 or 3 feet) recumbent fold is seen clearly at Locality 43-7 (Figure 4).

The collapse structures are always associated with the "fullers earth" type of mudrock. Locally portions of the mudrock have been destroyed leaving behind a residuum of soft clay. The undisturbed mudrock forms rounded and irregular pods (Figure 5). Between the pods the overlying sediments collapse to produce small synclines. Over the pods small anticlines may form because of the let down of the sediments on either side.

Nature of the Residuum

The residuum at Locality 43-7 (Figure 2, number 9) is a light olive gray (5Y 6/1, damp) massive clay with moderate reddish brown (10R 4/6, damp) stain along many irregular surfaces. At Locality

9-10 (Figure 3, number 6B) the residuum is more iron stained so that the whole mass is essentially a dark yellowish orange (10YR 6/6). Both clays have considerable plasticity as opposed to the adjacent pods of non-plastic "fullers earth".

Mineralogically the residuum consists of montmorillonite, kaolonite, clay mica, and a small amount of goethite. One sample collected close to the "fullers earth" body contained a small amount of ordered opal. An unidentified mineral with a d spacing of about 4.7 Å may be septechlorite (Table 2).

TABLE 1. Approximate porosity, bulk density, and approximate specific gravity of two samples of almost pure opal mudrock.

Sample No.	Air Dry Weight	Sat. Wt. Kerosene	Susp. Wt.	App. Porosity	Bulk Den. gms./cc	App. Sp. Gr.
43-7-5	15.12	23.49	9.65	60.5	0.875	2.21
9-10-4	14.93	25.29	9.55	65.7	0.758	2.21

Kerosene Sp. Gr. = 0.8. Specimens saturated at 29.5" vacuum plus 24 hour soak.

Of interest in the residuum is the rather high percentage of kaolinite, a mineral that usually is absent or present only in very small quantities in the mudrock.

The residuum from the two localities studied is not only of very similar composition, but the individual components occur in about the same amounts. Table 2 illustrates a measure of abundance of the three major minerals-montmorillonite, clay mica, and kaolinite. In addition the ratio of montmorillonite to montmorillonite plus kaolinite illustrates the similarity of the residuum of the two localities.

Origin of Slump Structures

The synclines are of slump origin because the field relationships show that where the "fullers earth" mudrock has been destroyed the overlying beds have been let down. The anticlines are cored by the undisturbed mudrock and have formed because the beds on either side of the crest have been let down.

The major problem is the means by which the "fullers earth" mudrock is destroyed. X-ray data (Table 2) show that the material interpreted in the field as a residuum has essentially no opal. Apparently the opal has been removed from the "fullers earth" mudrock leaving behind the other components of the mudrock as a residuum. The data further suggest that kaolinite has been formed in the residuum. This, however, may be more apparent than real since kaolinite does occur in small quantities in some of the associated opal-bearing sediments. The large quantities of kaolinite in the residuum may simply be an upgrading phenomenon.

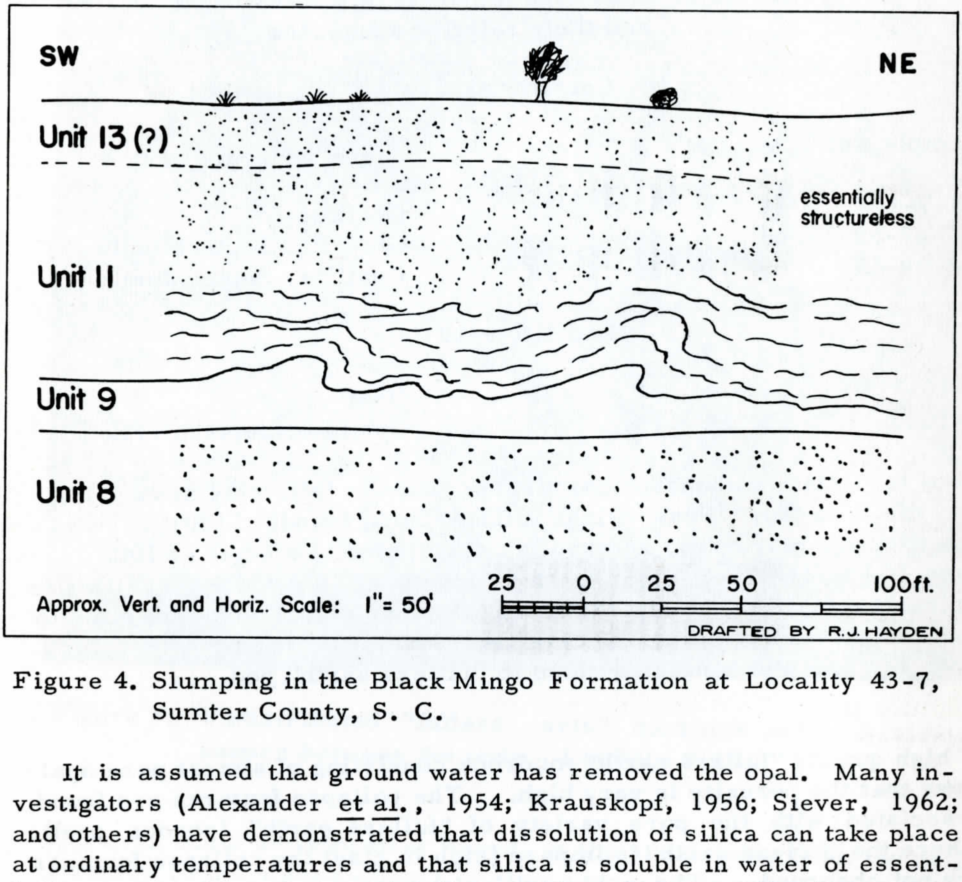

Figure 4. Slumping in the Black Mingo Formation at Locality 43-7, Sumter County, S. C.

It is assumed that ground water has removed the opal. Many investigators (Alexander et al., 1954; Krauskopf, 1956; Siever, 1962; and others) have demonstrated that dissolution of silica can take place at ordinary temperatures and that silica is soluble in water of essentially any pH although the solubility of silica rises rapidly above pH 9. This means that silica can be removed by common ground water at ordinary temperatures and pH values.

Siever (1962, p. 131) found the solubility of synthetic opal to be about 120 p.p.m. at 25°C. The synthetic opal gave an amorphous silica x-ray pattern (p. 129). Opal from the Black Mingo Formation is ordered (unidimensional disordered cristobalite) and gives a characteristic x-ray pattern. It is assumed that the solubility of the ordered opal would be slightly less than that of "amorphous" opal; however, no data are available on this problem.

Solution of the opal by ground water would probably be a function of the rate of ground water movement, which in turn is controlled by the porosity and permeability of the mudrock. No data are available on permeability. Porosity determinations (Table 1) on two samples

TABLE 2. Clay size minerals of the residuum and their relative abundance 1/

Sample No.	M	CM	K	M/M+K 2/	Other Minerals
Locality 43-7					
43-7-4	54	6	40	58	Goethite
HJ-27-62	63	9	28	70	Goethite, Septechlorite (?)
HJ-29-62	69	11	20	78	Goethite, Septechlorite (?)
Locality 9-10					
9-10-3 3/	66	7	27	71	Opal
9-10-5	62	25	13	82	Goethite, Septechlorite (?)

Note 1. Relative abundance of montmorillonite (M), clay mica (CM), and kaolinite (K). Peak height (minus background) of (001) of montmorillonite, clay mica, and kaolinite computed to a basis of 100.
Note 2. M/M +K = a ratio of peak height of (001) Montomorillonite (minus background) on Mg saturated (ethylene glycol solvated) slide to peak height (minus background) of (001) kaolinite.
Note 3. Samples collected close to "fullers earth" pod.

of high quality "fullers earth" mudrock consisting of almost pure opal show that the porosity is very high. The collapse features are found associated with the pure variety of "fullers earth" (porous opal). Where the "fullers earth" is impure (high in clay) the collapse features are not observed. The montmorillonite particles may clog the pores and prevent the solution of the opal.

Adjacent sand units are strong potential avenues for water movement. They could effectively carry away silica-laden waters from the mudrock. It is interesting to note that pockets of silicified shell fragments and thin layers of buhrstone are common in sands interbedded with the "fullers earth" mudrock.

The collapse structures have been noted only in dissected areas where the ground water gradient would be expected to be high. In the Low Country of Georgetown and Williamsburg counties collapse structures have not been seen even though the typical "fullers earth" mudrock is well exposed, as at Lower Bridge on Black River in Williamsburg County. Auger holes drilled by the Division of Geology, South

Figure 5. Undistributed "fullers earth" mudrock pods. Residuum occurs between the pods. Locality 9-10.

Carolina State Development Board, in the areas away from the major streams do not show evidence of slump structures or montmorillonite residuum. (Some sink holes are found in the outcrop area of the Black Mingo Formation. These are apparently formed by removal of calcium carbonate from the calcareous part of the Black Mingo or else from the calcareous Duplin Formation.)

The time of slump is unknown, but blanket deposits (sands and gravels) of Pleistocene or possibly Pliocene age have been involved.

More recent wind blown sands do not show evidence of slump. So far as is known there is no topographic expression of the slump features.

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STRATIGRAPHY OF THE NEOGENE DEPOSITS, LOWER NEUSE ESTUARY, NORTH CAROLINA

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ABSTRACT

In the past the Neogene (Post-Oligocene) deposits exposed along the Neuse Estuary downstream from New Bern have been divided into a Pliocene formation (Croatan) and a Pleistocene formation (Pamlico or Chowan).

Present field investigations have demonstrated that the classic deposits of the Croatan interfinger with and represent a facies of the Pleistocene complex. The "Croatan" formerly was considered Pliocene in age because of the abundance of contained reworked "older" fossils.

Older deposits (Pliocene?) not originally included in the Croatan Formation outcrop upstream along the banks of the Neuse near James City in Craven County. To these deposits the name "James City Formation" is herein applied.

It is considered incorrect and confusing to use the term Pamlico in a geormorphic as well as a stratigraphic sense. Further it is judged that the Pamlico was not adequately described as a lithologic unit. Therefore, "Pamlico" is rejected as a stratigraphic entity, but is tentatively retained as a name for the relatively flat seaward-sloping terrace-plain which lies below an elevation of 25 to 30 feet above present sea level.

The Late Pleistocene deposits of the lower Neuse Estuary which stratigraphically and unconformably overlie the James City beds are referred to a newly designated unit, the Flanner Beach Formation.

INTRODUCTION

General Statement

Generally the deposits exposed along the banks of the Neuse Estuary, downstream from New Bern (Fig. 1), have been divided into two formations. The older of these formations (Pliocene?) has been termed the "Croatan", and the younger (Pleistocene) generally now is regarded as representing the "Pamlico Formation."

The type Croatan exposures occur along the south bank of the Neuse River near the settlement of Croatan in Craven County, North Carolina. The age of this formation and its stratigraphic relationship with other deposits of the area, the "Pamlico Formation"(Pleistocene), has never been clearly defined.

As a part of a biostratigraphic study of the Neogene deposits of the Carolina Coastal Plain the "Croatan" and "Pamlico" formations were investigated by the authors. All exposures in the Croatan type area were closely examined and their relationships were determined in the field. Subsequently, the sediments and faunas of these deposits were analyzed in an effort to determine the depositional environments and age relationships.

The present paper is a progress report concerned only with the stratigraphic relationship of the exposures along the estuary. The paleoecology, paleontology and regional stratigraphy of these deposits will be discussed in later reports now being prepared by the authors and by James Howard of the University of Houston.

Location of exposures examined by the authors are plotted on a map of the lower Neuse River (Fig. 2). Other exposures in pits in Craven County recorded by earlier workers could not be located and are assumed to no longer exist.

As a result of the present field and laboratory study and an intensive examination of the literature pertaining to the problem, the present authors concluded that the name Croatan as currently used has no stratigraphic validity and should be suppressed. Further, it is concluded that use of the term Pamlico in both a geomorphic and stratigraphic sense is unwarranted.

The older (Pliocene?) deposits of the lower Neuse Estuary are redefined herein and named the "James City Formation." "Pamlico" is rejected as a stratigraphic term and late Pleistocene deposits of the lower Neuse Estuary which uncomformably overlie the James City beds are referred to as a newly designated unit, the "Flanner Beach Formation." The term "Pamlico" is tentatively retained for the relatively flat seaward-sloping terrace-plain which lies below an elevation of 25 to 30 feet above present sea level and which possibly can be traced from Virginia to Florida.

Acknowledgments

This project was financially supported by grants from the National Science Foundation.

Mansfield's Neuse River macrofaunal collections were made available to the authors at the National Museum by Harald Rheder and Druid Wilson.

Hobart W. C. Furbunch assisted with the field work.

BRIEF RESUMÉ OF PAST WORK

The Croatan Formation was named by Dall (1892, p. 209) for fossiliferous marine sediments exposed along the banks of the Neuse River east of New Bern, near Croatan, in Craven County, North Carolina. Dall referred the Croatan Formation, along with the Waccamaw Formation of South Carolina and the Caloosahatchee Formation of Florida, to the Floridan Group which he considered to be Pliocene in age. On the basis of a comparison of the Waccamaw and Croatan faunas Dall (1892, p. 215) concluded that the Croatan was a slightly younger Pliocene deposit than the Waccamaw Formation.

Prior to the time of Dall's study the Waccamaw and Croatan formations had been grouped by most geologists with other Neogene deposits of the Carolinas into the "Carolinian Beds" considered at the time to be Miocene in age. Among the earliest geologists to ascribe a

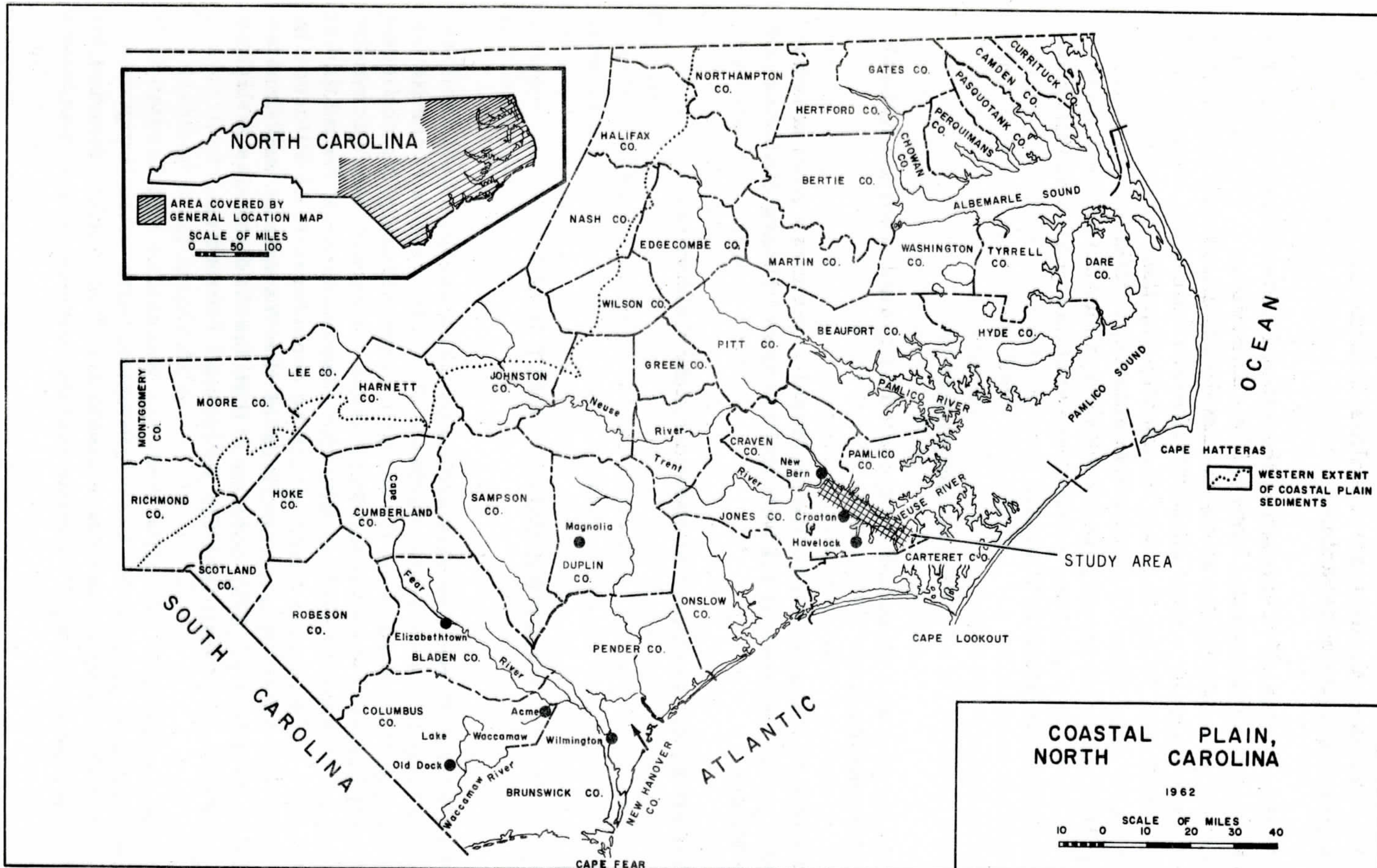

Figure 1. Location of Area Studied

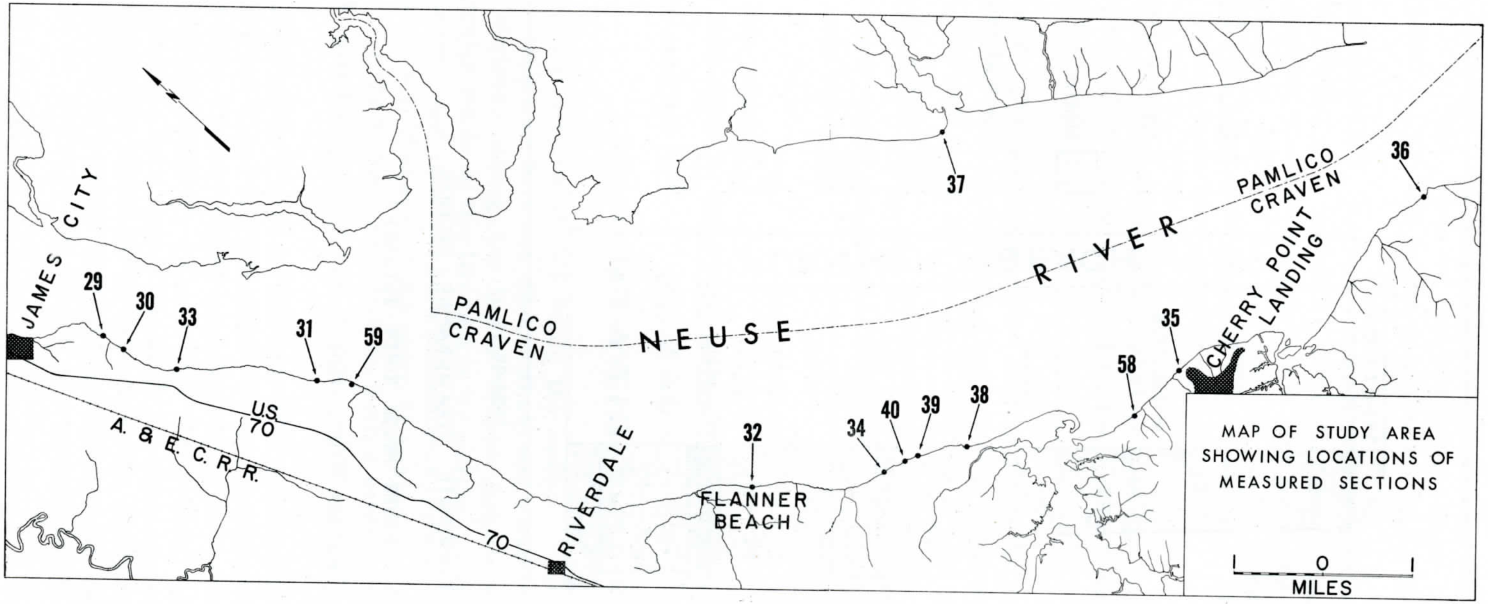

Figure 2. Location of Measured Sections.

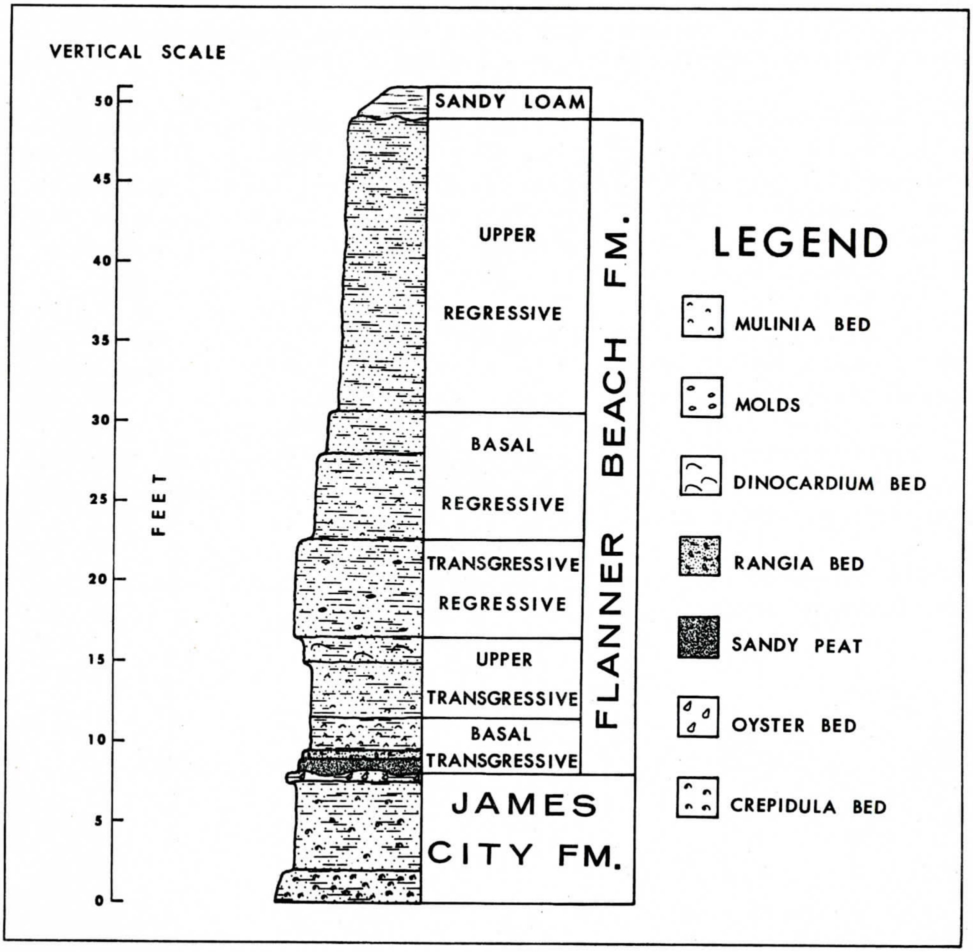

FIGURE 3

COMPOSITE STRATIGRAPHIC SECTION

(LOWER NEUSE RIVER ESTUARY)

Pliocene age to the Croatan Formation were Tuomey and Holmes (1857).

Miller (in Clark, 1912, p. 250-258 and 323-325) reviewed the Pliocene deposits of North Carolina. Miller in the same publication (p. 325) quoted the opinion of Julia Gardner that, "The Croatan beds are obviously newer than those of the Waccamaw, yet when compared with the admitted Pleistocene beds of South Carolina such as those of Simmons Bluff, the presence on the Neuse of 41 out of 96 species which have not been known later than the Pliocene forbids us to regard the fauna as later than Pliocene."

The Pamlico Formation was named by Stephenson (in Clark et al, 1912, p. 286) for deposits that cover the area adjacent to Pamlico Sound in North Carolina below an elevation of 25 feet.

Mansfield (1928, p. 135) thought that Dall had included both Pliocene and Pleistocene species in his Croatan faunal list. Mansfield recognized an unconformity between the Pliocene and Pleistocene at three sections located 11, 12 and 15 miles downstream from New Bern (Fig. 4), and subsequently restricted use of the name Croatan to the Pliocene beds below the unconformity.

In 1936 (p. 665) Mansfield described and discussed an exposure of the "Croatan Formation" located on the Neuse River two miles downstream from James City.

Richards (1950) summarized the geology of the North Carolina Coastal Plain and included a discussion of "Croatan" and "Pamlico" deposits exposed along the Neuse River.

Du Bar (1959) discussed the age and stratigraphic relationships of the "Croatan" and Waccamaw formations.

DISCUSSION OF STRATIGRAPHIC NOMENCLATURE

Observations of Earlier Workers

During the course of this study the authors became aware of certain discrepancies between their observed field relationships of the deposits exposed along the lower Neuse and statements concerning these deposits made in the literature by earlier workers. It also became apparent that considerable confusion exists concerning the exact stratigraphic significance of the term "Croatan". Further, the wisdom of using the term "Pamlico" in both a stratigraphic and geomorphic sense has been questioned by the senior author for some time.

These problems can be summarized by noting the following series of statements extracted from the literature and the subsequent series of observations by the authors. (Inclusions in parentheses are those of the present authors).

1. Dall, at the time (1892) he named the Croatan deposits, apparently had never seen the exposures on the lower Neuse. This is indicated by Dall's statement (1892, p. 204), "In the

autumn of 1891 Mr. Johnson (Charles W.), under the direction of Mr. (Joseph) Wilcox (Curator of the Museum of the Wagner Free Institute of Science), after conferring with the writer (Dall), undertook the search for genuine Pliocene beds in South Carolina."

According to Dall (1892, p. 205) Mr. Johnson, after completing his work in South Carolina, went up to the Neuse where he made collections at localities 13 and 15 miles downstream from New Bern.

Dall at no place refers to collections that he (Dall) made from the lower Neuse. Apparently all his conclusions were based on the collections and notes of Mr. Johnson.

2. Although Dall, in naming the "Croatan beds", apparently intended to apply the name to all the exposures along the lower Neuse, there is no evidence that either he or Charles Johnson were aware of the exposures upstream near James City. Referring to the deposits examined by Johnson, Dall wrote (1892, p. 209), "For those which are found along the estuary of the Neuse River the local Indian name of Croatan beds may be used." Dall reported only two sections measured and described by Johnson:

Thirteen miles below New Bern
3. Soil and ferruginous sand, 10 feet
2. Ferruginous sandy clay, 10 to 12 feet
1. Bluish clay with fossils (Pliocene), 5 to 6 feet

Fifteen miles below New Bern at the mouth of Slocum's Creek
3. Soil and ferruginous sand, 10 feet
2. Ferruginous sandy clay, 10 feet
1. Blue sandy clay and yellow sand with shells, 4 to 5 feet

3. When Mansfield (1928, p. 135) restricted use of the name Croatan to beds on the Neuse that are truly Pliocene, he referred only to the area 11 to 15 miles downstream from New Bern. It is apparent that at that time he was unaware of "Croatan deposits" upstream at James City by his later (1936, p. 665) reference to the fact that the "new locality," No. 13812, on the right bank of Neuse River, two miles below James City was called to his attention by S. F. Blake, and that he and MacNeil made collections there in 1936.

4. Mansfield in reference to locality No. 13812, two miles south of James City, determined the thickness of the "Croatan" to be

15 feet. Richards (1950, p. 33) concurred that the "Croatan" is 15 feet thick at that locality.

5. Mansfield stated (1928, p. 135) that the Pliocene-Pleistocene contact could be observed at two localities on the Neuse--"one about 11 miles below New Bern (Section 3, Fig. 4) and the other about 15 miles below New Bern (Section 4, Fig. 4)."

   Mansfield described the Pliocene as a coarse ferruginous more or less fossiliferous sand that rises to an observed maximum height of four feet above the beach. He stated that these Pliocene beds, the "Croatan Formation", were overlain unconformably by the Pleistocene which he tentatively placed in the Chowan Formation.

6. Richards (1950, p. 33) stated that the unconformity between the "Pamlico" (Mansfield's Chowan Formation) and the "Croatan beds" could no longer be observed at Mansfield's locality No. 3 (11 miles below New Bern) because it had been obliterated by river erosion. Richards added that at localities between 12 and 15 miles downstream from New Bern it was sometimes difficult to separate the "Croatan" from the "Pamlico".

7. Stephenson (in Clark et. al, p. 286) described the type area of the Pamlico Formation as a terrace-plain in the vicinity of Pamlico Sound, "--away from whose shores the terrace-plain forming the surface extends as broad, nearly level, stretches of lowland." He further stated that the formation covered most of Pamlico County. He pointed out that the Pamlico Terrace had been traced through Virginia and Maryland.

7b. The materials of the Pamlico Formation were described by Stephenson as, "fine sandy loams, sands and clays and to a limited extent of gravels." He listed the thickness as 15 to 20 feet.

7c. Stephenson mentioned only one exposure of his typical Pamlico. This was an outcrop noted by B. L. Johnson at the pier of the Norfolk Southern Railroad at Oriental, Pamlico County, Johnson described the section as, "several feet of clay overlain by one foot of dark to black soil."

7d. It is apparent that Stephenson had not definitely observed marine fossils in the type Pamlico by his statement (p. 287): "But little is known regarding the fossil contents of the deposits. It is certain that marine shell beds of Pleistocene age underlie portions of the area. It is possible that much of the region covered by the Pamlico beds was under water during parts of the Pleistocene time proceeding the deposition of the Pamlico material. In this case some of the Pleistocene shell beds occurring at shallow depths beneath the surface are in all probability older than the Pamlico Formation."

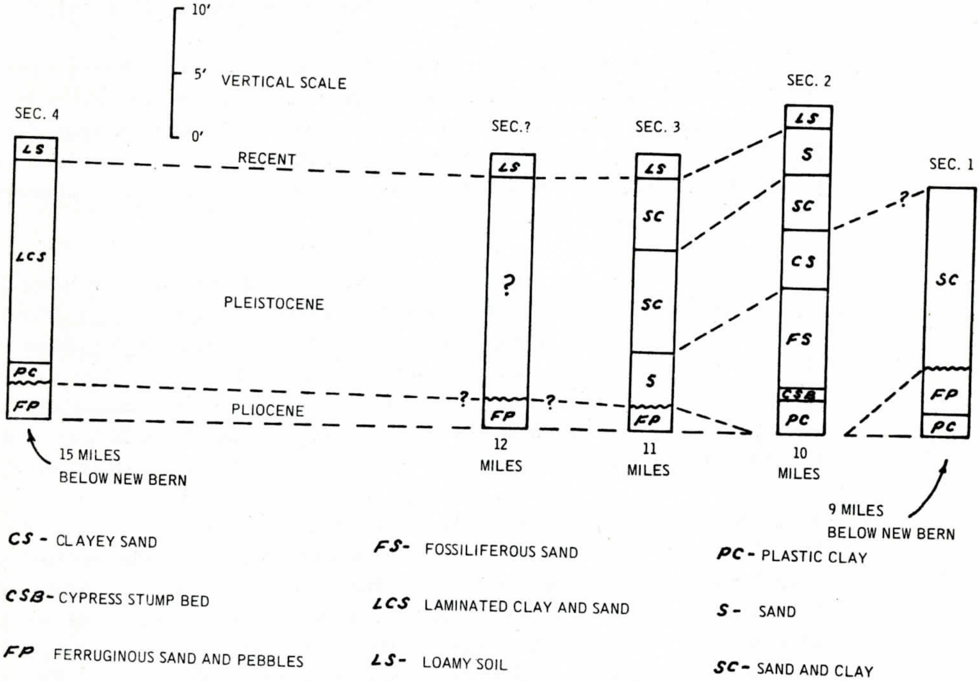

FIG.4

DETAILED COLUMNAR SECTIONS AS INTERPRETED BY

W. C. MANSFIELD (1928, p. 136)

Critique of Earlier Work

Judging from the evidence offered by Dall's writings (1892) the type locality of the "Croatan Formation" is the area of exposures along the Neuse River between points approximately 11 and 15 miles downstream from New Bern. It also seems apparent that Dall included the entire stratigraphic section represented by these exposures in his "Croatan beds." Thus, there is no doubt, as pointed out by Mansfield, later (1928), that some late Pleistocene deposits were included in Dall's original definition of the Croatan.

More importantly, it cannot be shown that true Pliocene or prelate Pleistocene deposits were actually exposed in this area at the time Mr. Johnson made his collections. Neither Dall nor Johnson offered any evidence that an unconformity existed in the outcrop area or that a faunal difference existed between the lower and upper units of the two exposures studied.

Mansfield's citation (1928) that an unconformity existed in the area 11 to 15 miles downstream from New Bern (Dall's Croatan type area) cannot be supported today by field observation. It is, of course, possible that the outcrops have retreated sufficiently in face of stream erosion so that the unconformity is no longer exposed at the surface. The authors do not think that this is true, inasmuch as their efforts to locate the unconformity by digging pits five to six feet deep in the

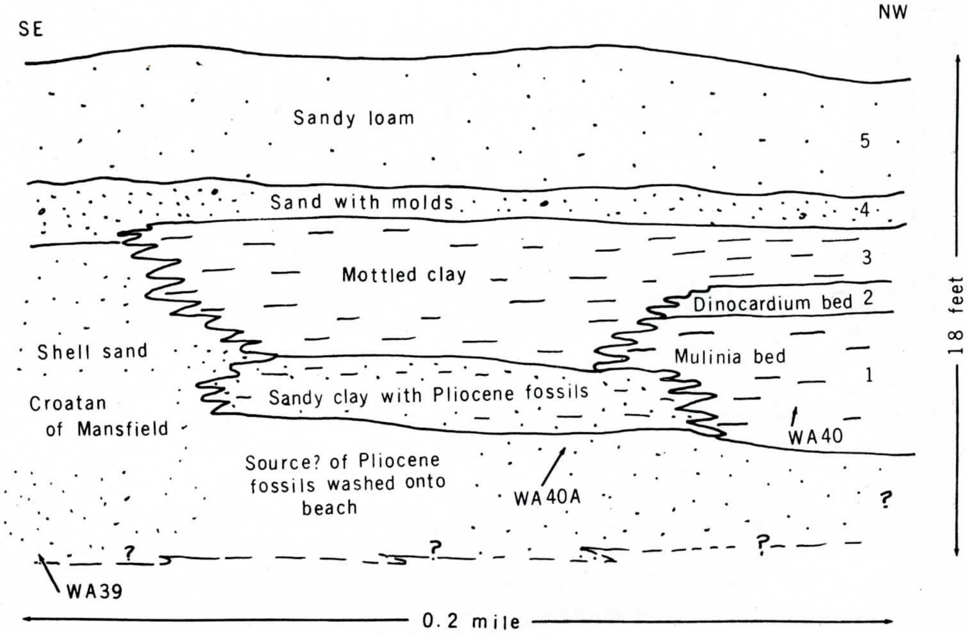

Figure 5. Stratigraphic relations of deposits in the vicinity of stations WA 40, WA 40A, and WA 39. All units exposed at WA 40 (1 through 5) were classified as Pleistocene by Mansfield (1928).

area did not meet with success. Further, the authors found that units very similar to those described by Mansfield as representative of the Croatan do occur in the same general area today, but are clearly a part of the Late Pleistocene complex. The authors found that deposits at Flanner Beach which Mansfield regarded as Late Pleistocene in age and which have been classified generally as Pamlico by later workers grade laterally into the units which Mansfield apparently restricted to the Pliocene (Fig. 4 and Fig. 6). Mansfield's apparent error is attributed to the fact that the lower sands in Dall's type "Croatan" area are late Pleistocene in age but contain numerous well preserved reworked Pliocene (?) fossils (Fig. 5).

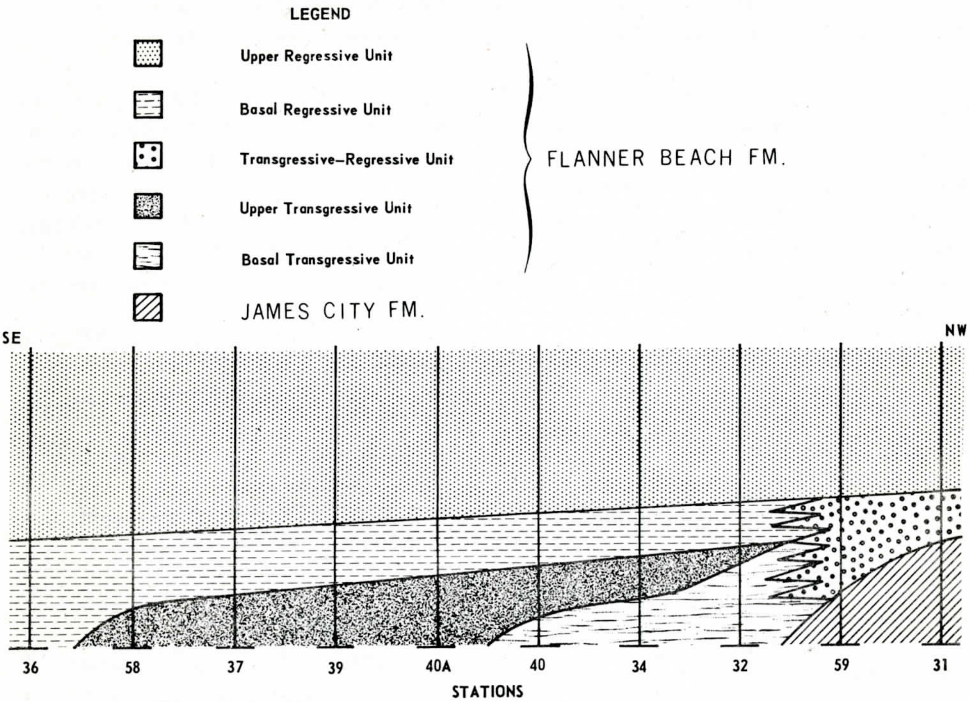

Figure 6. Diagrammatic cross section of Neogene deposits exposed along lower Neuse Estuary.

At the National Museum the authors examined Mansfield's macrofaunal collections which served as the basis for his Pliocene classification of the lower beds exposed along the lower Neuse Estuary. These collections are discussed below:

U. S. National Museum Collection No. 10,895a. Croatan Formation, lower 0-2 feet of Section 3 (Fig. 4), 11 miles below New Bern.

Pelecypoda

Chlamys n. sp. ? aff. C. eboreus Conrad
Crassinella dupliniana Dall
Diplodonta sp. cf. D. caloosaensis Dall

Anthozoa

Septastraea crassa (Holmes)

U. S. National Museum Collection No. 10,894. Croatan Formation, scattered fossils on the beach, 12 miles below New Bern (Fig. 4).

Pelecypoda

Anadara sp. aff. A. subsinuata (Conrad)
Anadara sp. eff. A. compyla Dall
Anadara n. sp. aff. A. plicatura (Conrad)
Cardita arata (Conrad)
Mulinia congesta (Conrad)
Noetia limula (Conrad) var.
Nuculana acuta (Conrad)?

Gastropoda

Crepidula fornicata (Linne)
Diodora cayenensis Lamarck

U. S. National Museum Collection No. 10,893. Croatan Formation, lower 2-4 feet of Section 4 (Fig. 4), 15 miles below New Bern.

Mansfield listed a total of 59 "Pliocene" and Pleistocene species from this unit, but definitely restricted 13 to a Pliocene or older age.

Pelecypoda

Anadara sp. aff. A. subsinuata Conrad
Cardita arata (Conrad)
Cardita perplana abbreviata Conrad
Caryocorbula inaequalis (Say)
Chama gardnerae Olsson and Harbison
Crassinella dupliniana Dall
Gemma trigona Dall
Mercenaria rileyi (Conrad)
Mulinia congesta (Conrad) not typical
Spisula subparilis Conrad var.

Gastropoda

Nassarius irrorata Conrad
Urosalpinx sp. aff. U. perrugatus Conrad

Anthozoa

Septastraea crassa Holmes

The species listed above do not constitute strong evidence of a Pliocene age when all the facts are considered. Some of the species were not identified definitely; others, such as Mulinia congesta, are extremely hard to distinguish from their Recent counterparts and indeed may not represent valid species. At least one species regarded by Mansfield as representative of the Pliocene, Septastraea crassa, occurs abundantly in Pleistocene deposits. Other species such as Crepidula fornicata and Diodora cayenensis were not regarded even by Mansfield as exclusively Pliocene in age.

Many of the "Pliocene" species in Mansfield's Croatan Formation are heavily worn suggesting considerable transportation and, in addition, show slight but consistently different preservation characteristics than the typical Late Pleistocene species in the same beds.

In addition, all of the specimens from Collection No. 10,894 were found scattered along the beach (Mansfield, 1927, p. 135). These fossils can be collected from the beach in the same area today (Mansfield's Station 12, Fig. 4). They obviously have been washed there by wave and current action of the present Neuse waters, although their exact source is still not known.

The fact that reworked Pliocene(?) fossils are present in the Late Pleistocene units (Flanner Beach Formation of this report) strongly suggests that true Pliocene(?) deposits were indeed nearby at the time of deposition of these deposits. This is verified by examination of the outcrops along the Neuse River near James City which, in part, represent an older Pliocene (?) deposit (James City Formation of this report). These are obviously the source beds of the reworked fossils in the Late Pleistocene deposits further downstream.

No exposed section of the Pliocene(?) deposits in the vicinity of James City is today anything near 15 feet in thickness. A section studied by the authors (WA 31) located very close to that described by Mansfield (1936) and Richards (1950) as being 15 feet thick is today about 24.5 feet thick, but only the lower 8.5 feet are Pliocene(?) in age (Croatan of Mansfield). The upper 16.0 feet lie unconformably on the Pliocene (?) and are included in the Flanner Beach Formation by the authors.

The formal use of the term Pamlico in both a geomorphic and stratigraphic sense is judged to be unwarranted by the authors. The only question seems to be to which sense, if either, the term should be restricted. Both are deeply ingrained in geologic literature and thinking. It is not certain that Stephenson intended to formally name the surface of his Pamlico Formation the Pamlico Terrace-Plain, but it seems that if the term is to be retained, it is in this sense that it has its best usage. Stephenson described the Pamlico essentially in terms of its surface expression. He gave only a vague lithologic description and did not cite an adequately described specific section to serve as a type for his formation. It is the opinion of the authors that the Pamlico Formation was not adequately described by Stephenson and that the name should be suppressed.

STRATIGRAPHIC RELATION OF THE FLANNER BEACH AND JAMES CITY FORMATIONS

The authors examined the area 11 to 15 miles downstream from New Bern very closely in an effort to locate the unconformity between the Pliocene and Pleistocene as reported by Mansfield (1928). Hand dug pits and auger holes failed to disclose any apparent unconformities.

The units of the type Flanner Beach section (WA 32) were traced into the area where Mansfield reported an unconformity(Fig. 4 and Fig. 5). At stations WA 34 and WA 40 sections occur essentially the same as that at Flanner Beach. At Station 39 the section is entirely different, being here represented by an unconsolidated yellowish-brown sand containing numerous "Croatan" fossils. The distance between stations WA 40 and WA 39 is merely 0.2 miles (Fig. 5).

Very detailed examination of the area clearly showed that the unquestioned Pleistocene Flanner Beach deposits of Station WA 40 grade laterally into those of Station WA 39 which apparently are the Pliocene Croatan deposits of Mansfield. Thus, it is obvious that the Croatan is simply a facies of the Flanner Beach Formation. Fossils at WA 39 which are generally regarded to be Pliocene species are clearly reworked from the James City Formation. Some of these species, such as *Cardita arata*, *Chama gardnerae*, *Cardita granulata*, *Chione cribraria*, *Noetia limula* and *Plicatula marginata* occur both in the sands of Station WA 39 and sandy layers and pockets in the undoubted Pleistocene deposits of Station WA 40.

In addition, the sands at WA 39 and those which are obviously an extension of this bed at WA 58 and WA 35 contain fossils, such as *Anadara ovalis*, typical of the Late Pleistocene.

Paleoecological analysis of the macrofauna and foraminiferal assemblages strongly suggests the Pleistocene deposits upstream from Station WA 39 lived in an enclosed brackish-water embayment whereas at Station WA 39 and downstream more open water beach conditions prevailed where waves, longshore currents and possibly tidal currents resulted in turbulence and considerable reworking of older Pliocene(?) sediments on the ocean floor and along the beach. A more detailed ecologic analysis will be presented in a later paper.

DESCRIPTION OF TYPE SECTIONS

James City Formation

The James City Formation crops out only at the extreme northwest end of the study area near James City in Craven County. All the exposures occur on the right bank of the Neuse Estuary.

Lithologically the formation is comprised primarily of unconsolidated calcareous sandy clays and argillaceous sands. Nearly all the units contain well preserved, abundant macro and microfaunas. The color varies in accordance with the degree of weathering; blue-gray on fresh surfaces to yellowish-brown and red-brown on highly weathered surfaces.

The thickness of the formation is not known, inasmuch as the base is nowhere exposed in the type area. The greatest exposed thickness is about 8.0 feet. The James City Formation is overlain disconformably by the Flanner Beach Formation. At places the actual contact between the formations is obscured by slumped sands and soils.

The type James City exposures are slightly undulatory, probably reflecting irregularities of the depositional surface. The formation dips below the surface at Station WA 59, about four miles downstream from James City, and does not reappear any place downstream, although it is probably close to the surface throughout the area.

The section designated as the specific type section of the formation is described below:

Type section of the James City Formation (Station WA 30 of this report). Right bank Neuse River, 0.6 mile downstream from Ft. Point

Light and 1.3 miles east of center of James City, New Bern Quadrangle, Craven County, North Carolina.

Unit	Description	Thickness (Feet)
Pleistocene		
Recent		
4.	Soil, arenaceous, brown	1.0
Flanner Beach Formation		
3.	Silt, arenaceous, quartz grains subangular, fine, argillaceous, micaceous, slightly consolidated, mottled grayish-orange (10 YR 7/4) and dark yellowish-orange (10 YR 6/6); no fossils observed	8.0
2.	Sand, quartz, fine to medium with some coarse grains, subangular, argillaceous, semiconsolidated, fair sorting, olive gray (5 Y 4/1) with streaks of dark yellow-orange (10 YR 6/6); possibly a few foraminifers	5.5
Unconformity		
Pliocene(?)		
James City Formation		
1.	Sand, quartz, fine to medium, silty, argillaceous, calcareous, slightly consolidated in lower 4.0 feet, more indurated in upper 1.0 foot due to weathering, pale yellowish-brown (YR 6/2) with light brown (5 YR 5/6); fossils abundant, well preserved in lower 4.0 feet, but occur only as molds in upper 1.0 foot, corals common, no evidence of extensive reworking	5.0

The James City Formation is also exposed at stations WA 29, 31, 33, and 59 (Fig. 2).

Flanner Beach Formation

The lithology of the Flanner Beach Formation is quite variable laterally and vertically. Generally, the formation is comprised of unconsolidated clays, sandy clays, argillaceous sands, and peaty sands and clays. Fossils occur in most all of the lower units, but are very rare or absent in the upper regressive sands.

In the vicinity of Flanner Beach the lower observed unit of the formation is a peaty sandy clay or argillaceous sand containing cypress logs and stumps. The base of this fresh-water unit has not been observed and an attempt to penetrate it with a hand auger at Flanner Beach failed at a depth of about six feet.

The lower fresh-water unit is typically dark gray whereas overlying units are predominantly brown, yellowish-brown or red-brown.

The thickest measured section is at Station WA 37 where about 35 feet of the formation is exposed. That the base at Station WA 37 is only a few feet below the surface is attested to by the abundance of James City fossils washing up onto the beach from a layer apparently just below water level.

The sedimentary sequence of the Flanner Beach Formation deduced from study of the fauna and sediments, is that of a transgressive-regressive cycle (Fig. 6). This sequence or some part thereof can be observed in each section. Five phases of the cycle are recognized:

(Youngest) 5. Upper regressive phase
4. Basal regressive phase
3. Transgressive-regressive phase
2. Upper transgressive phase
1. Basal transgressive phase

The section designated as the specific type section of the formation is described below:

Type section of the Flanner Beach Formation (Station WA 32 of this report). Right bank of Neuse River, Flanner Beach, Havelock Quadrangle, Craven County, North Carolina.

Unit	Description	Thickness (Feet)
Pleistocene		
	Flanner Beach Formation	
	Upper Regressive Unit	
5.	Clay, mottled orange to red-brown, arenaceous, some small pickets and lenses of argillaceous sand, quartz grains fine to medium subangular to subrounded, thinly bedded, moderately consolidated; no fossils observed	8.5
	Basal Regressive Unit	
4C.	Clay, red-brown, weathers to a dull rust-brown, massive well consolidated, fine to very fine, subangular to subrounded quartz grains; pelecypod molds stained with limonite common	3.0
4B.	Sand, argillaceous, calcareous, red-brown, fine to very fine, subangular to subrounded quartz grains, small aggregates of hematite, unconsolidated; molluscan fossils abundant and well preserved, <u>Mulinia lateralis</u> particularly abundant	1.5
4A.	Clay, arenaceous, greenish blue-gray, weathers olive drab, massive, compact, medium to very fine, subangular to subrounded quartz grains; sand occurs in small pickets, light gray, granular to very fine, subangular to subrounded, clear to frosted, some phosphatic pebbles and carbonized plant remains, micaceous, unconsolidated; sorting coefficient for the clay is 1.655; fossils not common - plant remains and a few shell fragments	2.0
	Upper Transgressive Unit	
3.	Sand, greenish-brown, weathers red-brown, argillaceous, moderately consolidated, medium	

Unit	Description	Thickness (Feet)
	to fine, subangular to subrounded quartz grains; fossils abundant, show slight degree of current orientation, Dinocardium robustum particularly characteristic; coefficient of sorting is 1.893. . . .	0.3
	Lower Transgressive Unit	
2.	Sand, argillaceous, greenish-brown, weathers dark brown, clear to dull, granular to fine quartz grains, fairly compact, coefficient of sorting is 1.641; Rangia cuneata abundant	0.4
1.	Sand, purple-black, weathers pinkish gray with patches of yellow-brown stain, argillaceous, peaty, clear to dull, fine to very fine, subangular to subrounded quartz grains, chunky, massive, breaks easily with earthy fracture, sorting coefficient is 1.708; carbonized plant remains common but marine invertebrate fossils not observed.	3.0

In the type area the Flanner Beach Formation can be differentiated from the James City Formation by the following criteria:

1. Flanner Beach Formation lies stratigraphically above and disconformably upon the James City Formation.

2. Marine units of the Flanner Beach Formation are generally more sandy and less calcareous than those of the James City Formation.

3. The Flanner Beach Formation contains a high percentage of nonmarine units.

4. The Flanner Beach Formation contains no extinct species which can be shown to be in place.

5. The Flanner Beach Formation was deposited in brackish and fresh water, whereas the James City Formation was deposited in a very slightly restricted embayment of the sea at a depth of 40 to 50 feet.

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COPPER Kα: $\lambda = 1.5418$ Å

2θ	0.0000	0.0250	0.0500	0.0750	0.1000	0.1250	0.1500	0.1750	0.2000	0.2250	2θ	0.2500	0.2750	0.3000	0.3250	0.3500	0.3750	0.4000	0.4250	0.4500	0.4750
2	44.1716	43.6263	43.0943	42.5752	42.0684	41.5735	41.0901	40.6179	40.1564	39.7053	2	39.2641	38.8327	38.4107	37.9977	37.5935	37.1979	36.8105	36.4310	36.0593	35.6952
3	29.4496	29.2062	28.9669	28.7315	28.4998	28.2719	28.0475	27.8268	27.6094	27.3954	3	27.1848	26.9773	26.7730	26.5717	26.3735	26.1782	25.9858	25.7961	25.6093	25.4251
4	22.0891	21.9520	21.8166	21.6828	21.5506	21.4201	21.2911	21.1636	21.0377	20.9133	4	20.7903	20.6688	20.5487	20.4300	20.3126	20.1966	20.0819	19.9685	19.8564	19.7455
5	17.6733	17.5855	17.4985	17.4123	17.3270	17.2426	17.1589	17.0761	16.9940	16.9128	5	16.8323	16.7526	16.6736	16.5954	16.5179	16.4411	16.3651	16.2897	16.2150	16.1411
6	14.7298	14.6688	14.6082	14.5482	14.4886	14.4295	14.3709	14.3128	14.2551	14.1979	6	14.1412	14.0849	14.0291	13.9737	13.9187	13.8642	13.8101	13.7564	13.7031	13.6503
7	12.6277	12.5828	12.5382	12.4940	12.4500	12.4064	12.3631	12.3201	12.2773	12.2349	7	12.1928	12.1509	12.1094	12.0681	12.0271	11.9864	11.9460	11.9058	11.8659	11.8263
8	11.0513	11.0169	10.9828	10.9488	10.9151	10.8816	10.8482	10.8151	10.7822	10.7495	8	10.7170	10.6846	10.6525	10.6206	10.5888	10.5573	10.5259	10.4948	10.4638	10.4329
9	9.8255	9.7983	9.7713	9.7445	9.7178	9.6912	9.6648	9.6385	9.6123	9.5864	9	9.5605	9.5348	9.5092	9.4838	9.4585	9.4333	9.4083	9.3834	9.3586	9.3340
10	8.8451	8.8231	8.8012	8.7794	8.7577	8.7362	8.7147	8.6933	8.6721	8.6510	10	8.6299	8.6090	8.5881	8.5674	8.5467	8.5262	8.5058	8.4854	8.4652	8.4450
11	8.0431	8.0249	8.0068	7.9888	7.9709	7.9530	7.9353	7.9176	7.9000	7.8824	11	7.8650	7.8476	7.8303	7.8130	7.7959	7.7788	7.7618	7.7449	7.7280	7.7112
12	7.3750	7.3597	7.3445	7.3294	7.3143	7.2993	7.2843	7.2694	7.2546	7.2398	12	7.2251	7.2104	7.1958	7.1813	7.1668	7.1524	7.1380	7.1237	7.1095	7.0953
13	6.8099	6.7969	6.7839	6.7710	6.7581	6.7453	6.7325	6.7198	6.7071	6.6945	13	6.6819	6.6694	6.6569	6.6445	6.6321	6.6198	6.6075	6.5952	6.5830	6.5709
14	6.3256	6.3144	6.3032	6.2921	6.2810	6.2699	6.2589	6.2479	6.2370	6.2261	14	6.2152	6.2044	6.1936	6.1828	6.1721	6.1614	6.1508	6.1402	6.1296	6.1191
15	5.9061	5.8963	5.8866	5.8769	5.8672	5.8576	5.8480	5.8384	5.8288	5.8193	15	5.8098	5.8004	5.7910	5.7816	5.7722	5.7629	5.7536	5.7443	5.7351	5.7259
16	5.5391	5.5306	5.5220	5.5135	5.5050	5.4965	5.4880	5.4796	5.4712	5.4628	16	5.4545	5.4462	5.4379	5.4296	5.4214	5.4131	5.4049	5.3968	5.3886	5.3805
17	5.2155	5.2079	5.2003	5.1928	5.1852	5.1777	5.1702	5.1628	5.1553	5.1479	17	5.1405	5.1331	5.1257	5.1184	5.1111	5.1038	5.0965	5.0892	5.0820	5.0748
18	4.9279	4.9212	4.9144	4.9077	4.9009	4.8942	4.8876	4.8809	4.8742	4.8676	18	4.8610	4.8544	4.8478	4.8413	4.8347	4.8282	4.8217	4.8152	4.8088	4.8023
19	4.6708	4.6647	4.6586	4.6526	4.6465	4.6405	4.6345	4.6285	4.6226	4.6166	19	4.6107	4.6048	4.5988	4.5930	4.5871	4.5812	4.5754	4.5695	4.5637	4.5579
20	4.4394	4.4340	4.4285	4.4230	4.4176	4.4121	4.4067	4.4013	4.3959	4.3906	20	4.3852	4.3798	4.3745	4.3692	4.3639	4.3586	4.3533	4.3480	4.3428	4.3375
21	4.2302	4.2253	4.2203	4.2154	4.2104	4.2055	4.2006	4.1957	4.1908	4.1859	21	4.1810	4.1762	4.1713	4.1665	4.1617	4.1569	4.1521	4.1473	4.1425	4.1377
22	4.0402	4.0356	4.0311	4.0266	4.0221	4.0176	4.0131	4.0087	4.0042	3.9998	22	3.9953	3.9909	3.9865	3.9821	3.9777	3.9733	3.9689	3.9645	3.9602	3.9558
23	3.8667	3.8626	3.8584	3.8543	3.8502	3.8461	3.8420	3.8379	3.8338	3.8298	23	3.8257	3.8217	3.8176	3.8136	3.8095	3.8055	3.8015	3.7975	3.7935	3.7895
24	3.7078	3.7040	3.7002	3.6964	3.6927	3.6889	3.6851	3.6814	3.6776	3.6739	24	3.6702	3.6664	3.6627	3.6590	3.6553	3.6516	3.6479	3.6443	3.6406	3.6369
25	3.5617	3.5582	3.5547	3.5512	3.5478	3.5443	3.5408	3.5374	3.5339	3.5305	25	3.5270	3.5236	3.5202	3.5168	3.5133	3.5099	3.5065	3.5032	3.4998	3.4964
26	3.4270	3.4237	3.4205	3.4173	3.4141	3.4109	3.4076	3.4045	3.4013	3.3981	26	3.3949	3.3917	3.3886	3.3854	3.3822	3.3791	3.3759	3.3728	3.3697	3.3666
27	3.3023	3.2993	3.2963	3.2933	3.2903	3.2873	3.2844	3.2814	3.2784	3.2755	27	3.2725	3.2696	3.2667	3.2637	3.2608	3.2579	3.2550	3.2521	3.2492	3.2463
28	3.1866	3.1838	3.1810	3.1782	3.1755	3.1727	3.1699	3.1672	3.1644	3.1617	28	3.1589	3.1562	3.1535	3.1507	3.1480	3.1453	3.1426	3.1399	3.1372	3.1345
29	3.0789	3.0763	3.0737	3.0711	3.0686	3.0660	3.0634	3.0608	3.0583	3.0557	29	3.0532	3.0506	3.0481	3.0455	3.0430	3.0405	3.0379	3.0354	3.0329	3.0304
30	2.9785	2.9761	2.9737	2.9713	2.9689	2.9665	2.9641	2.9617	2.9593	2.9569	30	2.9545	2.9521	2.9497	2.9473	2.9450	2.9426	2.9402	2.9379	2.9355	2.9332
31	2.8847	2.8824	2.8802	2.8779	2.8756	2.8734	2.8711	2.8689	2.8667	2.8644	31	2.8622	2.8600	2.8577	2.8555	2.8533	2.8511	2.8488	2.8466	2.8444	2.8422
32	2.7968	2.7947	2.7925	2.7904	2.7883	2.7862	2.7841	2.7820	2.7799	2.7778	32	2.7757	2.7736	2.7715	2.7694	2.7673	2.7652	2.7632	2.7611	2.7590	2.7570
33	2.7143	2.7123	2.7103	2.7083	2.7063	2.7043	2.7024	2.7004	2.6984	2.6964	33	2.6945	2.6925	2.6905	2.6886	2.6866	2.6846	2.6827	2.6807	2.6788	2.6769
34	2.6367	2.6348	2.6330	2.6311	2.6292	2.6273	2.6255	2.6236	2.6217	2.6199	34	2.6180	2.6162	2.6143	2.6125	2.6106	2.6088	2.6070	2.6051	2.6033	2.6015
35	2.5636	2.5619	2.5601	2.5583	2.5566	2.5548	2.5530	2.5513	2.5495	2.5478	35	2.5460	2.5443	2.5425	2.5408	2.5391	2.5373	2.5356	2.5338	2.5321	2.5304
36	2.4947	2.4930	2.4913	2.4897	2.4880	2.4863	2.4847	2.4830	2.4814	2.4797	36	2.4781	2.4764	2.4748	2.4731	2.4715	2.4698	2.4682	2.4665	2.4649	2.4633
37	2.4295	2.4279	2.4264	2.4248	2.4232	2.4216	2.4201	2.4185	2.4169	2.4154	37	2.4138	2.4122	2.4107	2.4091	2.4076	2.4060	2.4045	2.4029	2.4014	2.3998
38	2.3679	2.3664	2.3649	2.3634	2.3619	2.3604	2.3589	2.3574	2.3559	2.3544	38	2.3530	2.3515	2.3500	2.3485	2.3471	2.3456	2.3441	2.3426	2.3412	2.3397
39	2.3094	2.3080	2.3066	2.3052	2.3037	2.3023	2.3009	2.2995	2.2981	2.2967	39	2.2953	2.2939	2.2925	2.2911	2.2897	2.2883	2.2869	2.2855	2.2841	2.2827
40	2.2540	2.2526	2.2513	2.2499	2.2486	2.2472	2.2459	2.2445	2.2432	2.2419	40	2.2405	2.2392	2.2379	2.2365	2.2352	2.2339	2.2326	2.2312	2.2299	2.2286
41	2.2013	2.2000	2.1987	2.1974	2.1961	2.1949	2.1936	2.1923	2.1910	2.1898	41	2.1885	2.1872	2.1860	2.1847	2.1834	2.1822	2.1809	2.1797	2.1784	2.1771
42	2.1511	2.1499	2.1487	2.1475	2.1463	2.1450	2.1438	2.1426	2.1414	2.1402	42	2.1390	2.1378	2.1366	2.1354	2.1342	2.1330	2.1318	2.1306	2.1294	2.1282
43	2.1034	2.1022	2.1011	2.0999	2.0988	2.0976	2.0964	2.0953	2.0941	2.0930	43	2.0918	2.0907	2.0895	2.0884	2.0872	2.0861	2.0849	2.0838	2.0827	2.0815
44	2.0579	2.0568	2.0557	2.0546	2.0535	2.0524	2.0512	2.0501	2.0490	2.0479	44	2.0468	2.0457	2.0447	2.0436	2.0425	2.0414	2.0403	2.0392	2.0381	2.0370
45	2.0145	2.0134	2.0123	2.0113	2.0102	2.0092	2.0081	2.0071	2.0060	2.0050	45	2.0039	2.0029	2.0018	2.0008	1.9997	1.9987	1.9976	1.9966	1.9956	1.9945
46	1.9730	1.9720	1.9709	1.9699	1.9689	1.9679	1.9669	1.9659	1.9649	1.9639	46	1.9629	1.9619	1.9609	1.9599	1.9589	1.9579	1.9569	1.9559	1.9549	1.9539
47	1.9333	1.9323	1.9314	1.9304	1.9294	1.9285	1.9275	1.9265	1.9256	1.9246	47	1.9236	1.9227	1.9217	1.9208	1.9198	1.9189	1.9179	1.9170	1.9160	1.9151
48	1.8953	1.8944	1.8935	1.8925	1.8916	1.8907	1.8898	1.8889	1.8879	1.8870	48	1.8861	1.8852	1.8843	1.8833	1.8824	1.8815	1.8806	1.8797	1.8788	1.8779
49	1.8590	1.8581	1.8572	1.8563	1.8554	1.8545	1.8536	1.8528	1.8519	1.8510	49	1.8501	1.8492	1.8484	1.8475	1.8466	1.8457	1.8448	1.8440	1.8431	1.8422
50	1.8241	1.8233	1.8224	1.8215	1.8207	1.8198	1.8190	1.8182	1.8173	1.8165	50	1.8156	1.8148	1.8139	1.8131	1.8122	1.8114	1.8106	1.8097	1.8089	1.8080
51	1.7907	1.7898	1.7890	1.7882	1.7874	1.7866	1.7858	1.7849	1.7841	1.7833	51	1.7825	1.7817	1.7809	1.7801	1.7793	1.7785	1.7777	1.7769	1.7761	1.7752
52	1.7586	1.7578	1.7570	1.7562	1.7554	1.7546	1.7539	1.7531	1.7523	1.7515	52	1.7507	1.7500	1.7492	1.7484	1.7476	1.7468	1.7461	1.7453	1.7445	1.7438
53	1.7277	1.7270	1.7262	1.7254	1.7247	1.7239	1.7232	1.7224	1.7217	1.7209	53	1.7202	1.7194	1.7187	1.7179	1.7172	1.7165	1.7157	1.7150	1.7142	1.7135
54	1.6981	1.6973	1.6966	1.6959	1.6952	1.6944	1.6937	1.6930	1.6923	1.6915	54	1.6908	1.6901	1.6894	1.6887	1.6879	1.6872	1.6865	1.6858	1.6851	1.6844
55	1.6695	1.6688	1.6681	1.6674	1.6667	1.6660	1.6653	1.6646	1.6639	1.6633	55	1.6626	1.6619	1.6612	1.6605	1.6598	1.6591	1.6584	1.6577	1.6570	1.6563
56	1.6421	1.6414	1.6407	1.6400	1.6394	1.6387	1.6380	1.6374	1.6367	1.6360	56	1.6354	1.6347	1.6340	1.6334	1.6327	1.6320	1.6314	1.6307	1.6300	1.6294
57	1.6156	1.6150	1.6143	1.6137	1.6130	1.6124	1.6117	1.6111	1.6104	1.6098	57	1.6091	1.6085	1.6079	1.6072	1.6066	1.6059	1.6053	1.6047	1.6040	1.6034
58	1.5901	1.5895	1.5889	1.5882	1.5876	1.5870	1.5864	1.5857	1.5851	1.5845	58	1.5839	1.5833	1.5826	1.5820	1.5814	1.5808	1.5802	1.5796	1.5789	1.5783
59	1.5655	1.5649	1.5643	1.5637	1.5631	1.5625	1.5619	1.5613	1.5607	1.5601	59	1.5595	1.5589	1.5583	1.5577	1.5571	1.5565	1.5559	1.5553	1.5547	1.5541
60	1.5418	1.5412	1.5406	1.5401	1.5395	1.5389	1.5383	1.5377	1.5372	1.5366	60	1.5360	1.5354	1.5348	1.5343	1.5337	1.5331	1.5325	1.5320	1.5314	1.5308

2θ	0.5000	0.5250	0.5500	0.5750	0.6000	0.6250	0.6500	0.6750	0.7000	0.7250	2θ	0.7500	0.7750	0.8000	0.8250	0.8500	0.8750	0.9000	0.9250	0.9500	0.9750
2	35.3383	34.9884	34.6455	34.3092	33.9793	33.6558	33.3383	33.0268	32.7210	32.4209	2	32.1262	31.8369	31.5527	31.2735	30.9992	30.7297	30.4649	30.2045	29.9486	29.6970
3	25.2435	25.0646	24.8881	24.7141	24.5425	24.3733	24.2065	24.0418	23.8795	23.7192	3	23.5612	23.4052	23.2513	23.0994	22.9494	22.8014	22.6553	22.5111	22.3686	22.2280
4	19.6359	19.5274	19.4202	19.3141	19.2092	19.1054	19.0028	18.9012	18.8007	18.7013	4	18.6029	18.5056	18.4093	18.3139	18.2196	18.1262	18.0338	17.9423	17.8517	17.7621
5	16.0677	15.9951	15.9231	15.8517	15.7810	15.7110	15.6415	15.5726	15.5044	15.4368	5	15.3697	15.3032	15.2373	15.1720	15.1072	15.0430	14.9793	14.9161	14.8535	14.7914
6	13.5979	13.5458	13.4942	13.4429	13.3920	13.3416	13.2915	13.2417	13.1924	13.1434	6	13.0948	13.0465	12.9986	12.9510	12.9038	12.8570	12.8104	12.7642	12.7184	12.6729
7	11.7869	11.7478	11.7090	11.6704	11.6320	11.5939	11.5561	11.5185	11.4812	11.4441	7	11.4072	11.3706	11.3342	11.2981	11.2621	11.2264	11.1910	11.1557	11.1207	11.0859
8	10.4023	10.3719	10.3416	10.3115	10.2816	10.2518	10.2223	10.1929	10.1636	10.1346	8	10.1057	10.0769	10.0484	10.0199	9.9917	9.9636	9.9357	9.9079	9.8803	9.8528
9	9.3095	9.2851	9.2608	9.2367	9.2127	9.1888	9.1651	9.1415	9.1180	9.0946	9	9.0713	9.0482	9.0251	9.0022	8.9794	8.9568	8.9342	8.9118	8.8894	8.8672
10	8.4250	8.4050	8.3852	8.3654	8.3457	8.3261	8.3067	8.2873	8.2680	8.2487	10	8.2296	8.2106	8.1916	8.1728	8.1540	8.1353	8.1167	8.0982	8.0797	8.0614
11	7.6945	7.6779	7.6613	7.6448	7.6284	7.6121	7.5958	7.5796	7.5634	7.5474	11	[illegible]	[illegible]	7.4996	7.4838	7.4680	7.4524	[illegible]	[illegible]	[illegible]	[illegible]

49	1.8590	1.8581	1.8572	1.8563	1.8554	1.8545	1.8536	1.8528	1.8519	1.8510
50	1.8241	1.8233	1.8224	1.8215	1.8207	1.8198	1.8190	1.8182	1.8173	1.8165
51	1.7907	1.7898	1.7890	1.7882	1.7874	1.7866	1.7858	1.7849	1.7841	1.7833
52	1.7586	1.7578	1.7570	1.7562	1.7554	1.7546	1.7539	1.7531	1.7523	1.7515
53	1.7277	1.7270	1.7262	1.7254	1.7247	1.7239	1.7232	1.7224	1.7217	1.7209
54	1.6981	1.6973	1.6966	1.6959	1.6952	1.6944	1.6937	1.6930	1.6923	1.6915
55	1.6695	1.6688	1.6681	1.6674	1.6667	1.6660	1.6653	1.6646	1.6639	1.6633
56	1.6421	1.6414	1.6407	1.6400	1.6394	1.6387	1.6380	1.6374	1.6367	1.6360
57	1.6156	1.6150	1.6143	1.6137	1.6130	1.6124	1.6117	1.6111	1.6104	1.6098
58	1.5901	1.5895	1.5889	1.5882	1.5876	1.5870	1.5864	1.5857	1.5851	1.5845
59	1.5655	1.5649	1.5643	1.5637	1.5631	1.5625	1.5619	1.5613	1.5607	1.5601
60	1.5418	1.5412	1.5406	1.5401	1.5395	1.5389	1.5383	1.5377	1.5372	1.5366

49	1.8501	1.8492	1.8484	1.8475	1.8466	1.8457	1.8448	1.8440	1.8431	1.8422
50	1.8156	1.8148	1.8139	1.8131	1.8122	1.8114	1.8106	1.8097	1.8089	1.8080
51	1.7825	1.7817	1.7809	1.7801	1.7793	1.7785	1.7777	1.7769	1.7761	1.7752
52	1.7507	1.7500	1.7492	1.7484	1.7476	1.7468	1.7461	1.7453	1.7445	1.7438
53	1.7202	1.7194	1.7187	1.7179	1.7172	1.7165	1.7157	1.7150	1.7142	1.7135
54	1.6908	1.6901	1.6894	1.6887	1.6879	1.6872	1.6865	1.6858	1.6851	1.6844
55	1.6626	1.6619	1.6612	1.6605	1.6598	1.6591	1.6584	1.6577	1.6570	1.6563
56	1.6354	1.6347	1.6340	1.6334	1.6327	1.6320	1.6314	1.6307	1.6300	1.6294
57	1.6091	1.6085	1.6079	1.6072	1.6066	1.6059	1.6053	1.6047	1.6040	1.6034
58	1.5839	1.5833	1.5826	1.5820	1.5814	1.5808	1.5802	1.5796	1.5789	1.5783
59	1.5595	1.5589	1.5583	1.5577	1.5571	1.5565	1.5559	1.5553	1.5547	1.5541
60	1.5360	1.5354	1.5348	1.5343	1.5337	1.5331	1.5325	1.5320	1.5314	1.5308

2θ	0.5000	0.5250	0.5500	0.5750	0.6000	0.6250	0.6500	0.6750	0.7000	0.7250
2	35.3383	34.9884	34.6455	34.3092	33.9793	33.6558	33.3383	33.0268	32.7210	32.4209
3	25.2435	25.0646	24.8881	24.7141	24.5425	24.3733	24.2065	24.0418	23.8795	23.7192
4	19.6359	19.5274	19.4202	19.3141	19.2092	19.1054	19.0028	18.9012	18.8007	18.7013
5	16.0677	15.9951	15.9231	15.8517	15.7810	15.7110	15.6415	15.5726	15.5044	15.4368
6	13.5979	13.5458	13.4942	13.4429	13.3920	13.3416	13.2915	13.2417	13.1924	13.1434
7	11.7869	11.7478	11.7090	11.6704	11.6320	11.5939	11.5561	11.5185	11.4812	11.4441
8	10.4023	10.3719	10.3416	10.3115	10.2816	10.2518	10.2223	10.1929	10.1636	10.1346
9	9.3095	9.2851	9.2608	9.2367	9.2127	9.1888	9.1651	9.1415	9.1180	9.0946
10	8.4250	8.4050	8.3852	8.3654	8.3457	8.3261	8.3067	8.2873	8.2680	8.2487
11	7.6945	7.6779	7.6613	7.6448	7.6284	7.6121	7.5958	7.5796	7.5634	7.5474
12	7.0811	7.0670	7.0530	7.0391	7.0252	7.0113	6.9975	6.9837	6.9701	6.9564
13	6.5588	6.5467	6.5347	6.5227	6.5108	6.4989	6.4870	6.4752	6.4635	6.4517
14	6.1086	6.0982	6.0877	6.0773	6.0670	6.0567	6.0464	6.0362	6.0259	6.0158
15	5.7167	5.7075	5.6984	5.6893	5.6803	5.6712	5.6622	5.6533	5.6443	5.6354
16	5.3724	5.3643	5.3563	5.3483	5.3403	5.3323	5.3243	5.3164	5.3085	5.3006
17	5.0676	5.0604	5.0533	5.0461	5.0390	5.0319	5.0249	5.0178	5.0108	5.0038
18	4.7959	4.7895	4.7831	4.7767	4.7703	4.7640	4.7576	4.7513	4.7450	4.7387
19	4.5521	4.5464	4.5406	4.5349	4.5291	4.5234	4.5177	4.5120	4.5064	4.5007
20	4.3323	4.3271	4.3218	4.3167	4.3115	4.3063	4.3011	4.2960	4.2909	4.2857
21	4.1330	4.1282	4.1235	4.1188	4.1141	4.1094	4.1047	4.1000	4.0953	4.0907
22	3.9515	3.9472	3.9429	3.9385	3.9342	3.9300	3.9257	3.9214	3.9171	3.9129
23	3.7856	3.7816	3.7776	3.7737	3.7698	3.7658	3.7619	3.7580	3.7541	3.7502
24	3.6333	3.6296	3.6260	3.6224	3.6187	3.6151	3.6115	3.6079	3.6043	3.6007
25	3.4930	3.4897	3.4863	3.4829	3.4796	3.4763	3.4729	3.4696	3.4663	3.4630
26	3.3634	3.3603	3.3572	3.3541	3.3510	3.3479	3.3448	3.3418	3.3387	3.3356
27	3.2434	3.2405	3.2376	3.2347	3.2318	3.2290	3.2261	3.2232	3.2204	3.2175
28	3.1318	3.1291	3.1264	3.1237	3.1211	3.1184	3.1157	3.1131	3.1104	3.1078
29	3.0279	3.0254	3.0229	3.0204	3.0179	3.0154	3.0129	3.0104	3.0079	3.0055
30	2.9308	2.9285	2.9261	2.9238	2.9215	2.9192	2.9168	2.9145	2.9122	2.9099
31	2.8400	2.8378	2.8356	2.8335	2.8313	2.8291	2.8269	2.8247	2.8226	2.8204
32	2.7549	2.7528	2.7508	2.7487	2.7467	2.7446	2.7426	2.7405	2.7385	2.7365
33	2.6749	2.6730	2.6710	2.6691	2.6672	2.6653	2.6633	2.6614	2.6595	2.6576
34	2.5996	2.5978	2.5960	2.5942	2.5924	2.5905	2.5887	2.5869	2.5851	2.5833
35	2.5287	2.5269	2.5252	2.5235	2.5218	2.5201	2.5184	2.5167	2.5150	2.5133
36	2.4617	2.4600	2.4584	2.4568	2.4552	2.4535	2.4519	2.4503	2.4487	2.4471
37	2.3983	2.3967	2.3952	2.3937	2.3921	2.3906	2.3891	2.3875	2.3860	2.3845
38	2.3383	2.3368	2.3353	2.3339	2.3324	2.3310	2.3295	2.3281	2.3266	2.3252
39	2.2813	2.2799	2.2786	2.2772	2.2758	2.2744	2.2730	2.2717	2.2703	2.2689
40	2.2273	2.2260	2.2247	2.2233	2.2220	2.2207	2.2194	2.2181	2.2168	2.2155
41	2.1759	2.1746	2.1734	2.1721	2.1709	2.1696	2.1684	2.1672	2.1659	2.1647
42	2.1270	2.1258	2.1246	2.1234	2.1222	2.1210	2.1199	2.1187	2.1175	2.1163
43	2.0804	2.0792	2.0781	2.0770	2.0758	2.0747	2.0736	2.0724	2.0713	2.0702
44	2.0359	2.0348	2.0338	2.0327	2.0316	2.0305	2.0294	2.0284	2.0273	2.0262
45	1.9935	1.9924	1.9914	1.9904	1.9893	1.9883	1.9873	1.9862	1.9852	1.9842
46	1.9529	1.9519	1.9509	1.9499	1.9490	1.9480	1.9470	1.9460	1.9450	1.9440
47	1.9141	1.9132	1.9122	1.9113	1.9103	1.9094	1.9084	1.9075	1.9065	1.9056
48	1.8770	1.8760	1.8751	1.8742	1.8733	1.8724	1.8715	1.8706	1.8697	1.8688
49	1.8414	1.8405	1.8396	1.8387	1.8379	1.8370	1.8361	1.8353	1.8344	1.8335
50	1.8072	1.8064	1.8055	1.8047	1.8039	1.8030	1.8022	1.8014	1.8006	1.7997
51	1.7744	1.7736	1.7728	1.7720	1.7712	1.7704	1.7696	1.7688	1.7681	1.7673
52	1.7430	1.7422	1.7414	1.7407	1.7399	1.7391	1.7384	1.7376	1.7368	1.7361
53	1.7127	1.7120	1.7113	1.7105	1.7098	1.7090	1.7083	1.7076	1.7068	1.7061
54	1.6837	1.6829	1.6822	1.6815	1.6808	1.6801	1.6794	1.6787	1.6780	1.6773
55	1.6557	1.6550	1.6543	1.6536	1.6529	1.6522	1.6516	1.6509	1.6502	1.6495
56	1.6287	1.6280	1.6274	1.6267	1.6261	1.6254	1.6248	1.6241	1.6234	1.6228
57	1.6027	1.6021	1.6015	1.6008	1.6002	1.5996	1.5989	1.5983	1.5977	1.5970
58	1.5777	1.5771	1.5765	1.5759	1.5753	1.5746	1.5740	1.5734	1.5728	1.5722
59	1.5536	1.5530	1.5524	1.5518	1.5512	1.5506	1.5500	1.5494	1.5488	1.5482
60	1.5302	1.5297	1.5291	1.5285	1.5280	1.5274	1.5268	1.5263	1.5257	1.5251

2θ	0.7500	0.7750	0.8000	0.8250	0.8500	0.8750	0.9000	0.9250	0.9500	0.9750
2	32.1262	31.8369	31.5527	31.2735	30.9992	30.7297	30.4649	30.2045	29.9486	29.6970
3	23.5612	23.4052	23.2513	23.0994	22.9494	22.8014	22.6553	22.5111	22.3686	22.2280
4	18.6029	18.5056	18.4093	18.3139	18.2196	18.1262	18.0338	17.9423	17.8517	17.7621
5	15.3697	15.3032	15.2373	15.1720	15.1072	15.0430	14.9793	14.9161	14.8535	14.7914
6	13.0948	13.0465	12.9986	12.9510	12.9038	12.8570	12.8104	12.7642	12.7184	12.6729
7	11.4072	11.3706	11.3342	11.2981	11.2621	11.2264	11.1910	11.1557	11.1207	11.0859
8	10.1057	10.0769	10.0484	10.0199	9.9917	9.9636	9.9357	9.9079	9.8803	9.8528
9	9.0713	9.0482	9.0251	9.0022	8.9794	8.9568	8.9342	8.9118	8.8894	8.8672
10	8.2296	8.2106	8.1916	8.1728	8.1540	8.1353	8.1167	8.0982	8.0797	8.0614
11	7.5314	7.5154	7.4996	7.4838	7.4680	7.4524	7.4368	7.4212	7.4058	7.3904
12	6.9428	6.9293	6.9158	6.9024	6.8890	6.8757	6.8624	6.8492	6.8361	6.8229
13	6.4401	6.4284	6.4168	6.4053	6.3938	6.3823	6.3709	6.3595	6.3482	6.3369
14	6.0056	5.9955	5.9855	5.9754	5.9654	5.9554	5.9455	5.9356	5.9257	5.9159
15	5.6265	5.6176	5.6088	5.6000	5.5912	5.5825	5.5738	5.5651	5.5564	5.5478
16	5.2928	5.2849	5.2771	5.2694	5.2616	5.2539	5.2461	5.2384	5.2308	5.2231
17	4.9968	4.9898	4.9829	4.9759	4.9690	4.9621	4.9552	4.9484	4.9416	4.9347
18	4.7325	4.7262	4.7200	4.7138	4.7076	4.7014	4.6953	4.6891	4.6830	4.6769
19	4.4951	4.4894	4.4838	4.4782	4.4726	4.4671	4.4615	4.4560	4.4504	4.4449
20	4.2806	4.2755	4.2705	4.2654	4.2603	4.2553	4.2503	4.2452	4.2402	4.2352
21	4.0860	4.0814	4.0768	4.0722	4.0676	4.0630	4.0584	4.0538	4.0493	4.0447
22	3.9086	3.9044	3.9002	3.8960	3.8918	3.8876	3.8834	3.8792	3.8750	3.8709
23	3.7463	3.7424	3.7385	3.7347	3.7308	3.7270	3.7231	3.7193	3.7155	3.7116
24	3.5971	3.5936	3.5900	3.5864	3.5829	3.5793	3.5758	3.5723	3.5688	3.5652
25	3.4597	3.4564	3.4531	3.4498	3.4465	3.4432	3.4400	3.4367	3.4335	3.4302
26	3.3326	3.3295	3.3265	3.3234	3.3204	3.3173	3.3143	3.3113	3.3083	3.3053
27	3.2147	3.2119	3.2090	3.2062	3.2034	3.2006	3.1978	3.1950	3.1922	3.1894
28	3.1051	3.1025	3.0998	3.0972	3.0946	3.0920	3.0893	3.0867	3.0841	3.0815
29	3.0030	3.0005	2.9981	2.9956	2.9932	2.9907	2.9883	2.9858	2.9834	2.9810
30	2.9076	2.9053	2.9030	2.9007	2.8984	2.8961	2.8938	2.8915	2.8892	2.8870
31	2.8182	2.8161	2.8139	2.8118	2.8096	2.8075	2.8053	2.8032	2.8011	2.7989
32	2.7344	2.7324	2.7304	2.7284	2.7263	2.7243	2.7223	2.7203	2.7183	2.7163
33	2.6557	2.6538	2.6519	2.6500	2.6481	2.6462	2.6443	2.6424	2.6405	2.6386
34	2.5815	2.5797	2.5779	2.5761	2.5743	2.5725	2.5708	2.5690	2.5672	2.5654
35	2.5116	2.5099	2.5082	2.5065	2.5048	2.5031	2.5014	2.4997	2.4980	2.4964
36	2.4455	2.4439	2.4423	2.4407	2.4391	2.4375	2.4359	2.4343	2.4327	2.4311
37	2.3830	2.3814	2.3799	2.3784	2.3769	2.3754	2.3739	2.3724	2.3709	2.3694
38	2.3237	2.3223	2.3209	2.3194	2.3180	2.3166	2.3151	2.3137	2.3123	2.3108
39	2.2676	2.2662	2.2648	2.2635	2.2621	2.2607	2.2594	2.2580	2.2567	2.2553
40	2.2142	2.2129	2.2116	2.2103	2.2090	2.2077	2.2064	2.2051	2.2038	2.2026
41	2.1634	2.1622	2.1610	2.1597	2.1585	2.1573	2.1560	2.1548	2.1536	2.1524
42	2.1151	2.1139	2.1128	2.1116	2.1104	2.1092	2.1081	2.1069	2.1057	2.1046
43	2.0691	2.0679	2.0668	2.0657	2.0646	2.0635	2.0623	2.0612	2.0601	2.0590
44	2.0251	2.0241	2.0230	2.0219	2.0208	2.0198	2.0187	2.0176	2.0166	2.0155
45	1.9832	1.9821	1.9811	1.9801	1.9791	1.9781	1.9770	1.9760	1.9750	1.9740
46	1.9430	1.9421	1.9411	1.9401	1.9391	1.9382	1.9372	1.9362	1.9352	1.9343
47	1.9047	1.9037	1.9028	1.9019	1.9009	1.9000	1.8991	1.8981	1.8972	1.8963
48	1.8679	1.8670	1.8661	1.8652	1.8643	1.8634	1.8625	1.8616	1.8607	1.8599
49	1.8327	1.8318	1.8310	1.8301	1.8292	1.8284	1.8275	1.8267	1.8258	1.8250
50	1.7989	1.7981	1.7972	1.7964	1.7956	1.7948	1.7939	1.7931	1.7923	1.7915
51	1.7665	1.7657	1.7649	1.7641	1.7633	1.7625	1.7617	1.7609	1.7601	1.7593
52	1.7353	1.7345	1.7338	1.7330	1.7323	1.7315	1.7307	1.7300	1.7292	1.7285
53	1.7054	1.7046	1.7039	1.7032	1.7024	1.7017	1.7010	1.7002	1.6995	1.6988
54	1.6766	1.6758	1.6751	1.6744	1.6737	1.6730	1.6723	1.6716	1.6709	1.6702
55	1.6488	1.6481	1.6475	1.6468	1.6461	1.6454	1.6448	1.6441	1.6434	1.6427
56	1.6221	1.6215	1.6208	1.6202	1.6195	1.6189	1.6182	1.6176	1.6169	1.6163
57	1.5964	1.5958	1.5951	1.5945	1.5939	1.5932	1.5926	1.5920	1.5914	1.5907
58	1.5716	1.5710	1.5704	1.5698	1.5692	1.5685	1.5679	1.5673	1.5667	1.5661
59	1.5477	1.5471	1.5465	1.5459	1.5453	1.5447	1.5441	1.5436	1.5430	1.5424
60	1.5246	1.5240	1.5234	1.5228	1.5223	1.5217	1.5212	1.5206	1.5200	1.5195

J. Robert Butler

TABLE OF d SPACINGS FROM 2.000° TO 60.975° 2θ IN 0.025 DEGREE INCREMENTS COPPER Kα RADIATION 1/

by

Jo E. Wilson
S. Duncan Heron, Jr.
Wm. J. Furbish

Duke University

With precision measurement of d spacings becoming routine, it is desirable to have readily available tables reading to the nearest 0.025 degrees 2θ. The accompanying table was prepared by solving the Bragg equation for 2θ using Copper Kα wave length of 1.5418 Å. Values were obtained on a digital computer using sin tables correct to 10^{-8} and a radian conversion factor correct to 10^{-7}.

Computations were made in the Duke University Computing Laboratory which is supported in part by the National Science Foundation.

1/ Copies of the table are available from SOUTHEASTERN GEOLOGY, Box 6665, College Station, Durham, North Carolina, at 50 cents per copy postpaid; 20% discount in lots of 10 or more.